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THE IMPROVEMENT OF THE MISSISSIPPI RIVER.*

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The Mississippi is above all things a silt-bearing stream, flowing through a bed of its own creation. It is never clear, even at its lowest; and at its floods it is charged with sediment to an enormous extent. This involves the following consequences: The banks are low and subject to overflow by all floods greater than the mean. Banks and bottom are friable, and, therefore, liable to degradation and erosion. The channel is shifting and unstable, and subject to obstruction by shoals.

The Mississippi, like all other streams, is composed of tortuous bends, which modify, in the most striking manner, the laws of its flow. In the portion of its course which we are considering it runs through a bed of comparatively recent origin. It is seldom that it encounters a portion of any formation older than that which constitutes its present flood-plain. At a few points the banks consist of bluffs of a quaternary formation, called by geologists loess, from a similar formation on the Rhine; at a few more, its bed trenches on another quaternary formation, called the "Port Hudson" clay, not very dissimilar to that of the present alluvium, and deposited by the river itself in its ancient state, at an epoch anterior to that of the present stream. It has been a much mooted question how great a part of the present bed is occupied by this

*This paper was prepared for the University of the City of New York. It is now published for the first time through the courtesy of the Faculty of that Institution.

older and harder clay; but the investigations of the Mississippi River Commission appear to point to the conclusion that the proportion is small.

The alluvium composing the banks and the bed is extremely variable in composition, being sometimes nearly pure sand, sometimes nearly pure clay, sometimes made up of both ingredients in all proportions. These different qualities of soil are disposed in strata of every variety of thickness.

Thus the banks are friable, but in very different degrees. Usually, however, even the toughest clay is underlaid by strata of lighter material, which, as will soon be seen, diminishes the resisting power of the stronger earth.

The theory of the completed flood-plain of a river is well known. The sediment brought from the torrential and fluvial parts is deposited on the bottom, and by overflow on the banks of the stream in its alluvial part; thus raising the upper portion of the flood-plain, and steepening its slope until the velocity of the water becomes sufficient to carry the load without diminution to the sea. Not every flood-plain is completed. Some are yet in a state of transition and have not attained stability.

Bends introduce a disturbing element into this process. The current, flowing with the normal, or even with a slightly accelerated velocity, encounters the resistance of the bank, say at *A* (see Fig. 1), placed at a somewhat abrupt angle to the course of the stream.

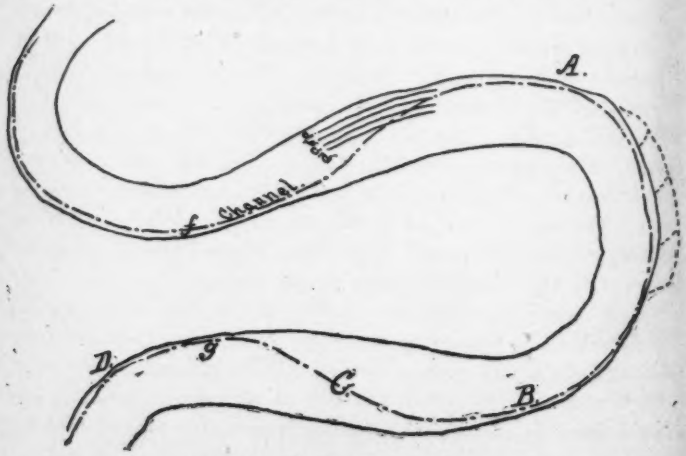

Fig. 1.

A portion of its energy is directed against the soft material composing the bank, promptly dislodges it and carries it a certain distance.

It is supposed that the normal velocity is sufficient, and no more, to carry to the sea the sediment brought to the alluvial portion from above. This will not prevent it from acting on the banks. Be the water never so highly charged, provided its fluidity be not materially impaired, when it encounters the bank at an abrupt angle, it will not fail to dislodge a portion of the material. This action is purely mechanical. It is the effect of direct impact, like the blow of a pickaxe or a hydraulic jet. The earthy matter thus committed to the water will not sink directly to the bottom. It will be carried a hundred or a thousand feet, or a mile, or ten miles, and eventually dropped, and this although there were no slackening of the velocity. By hypothesis the water was already loaded with all it could permanently transport, when it acquired this additional load, which must therefore be only temporary, *à fortiori* then must be deposited when the velocity is diminished. The "caving" action, as it is called, generally goes on for several miles throughout the bend, *A B*. The velocity is not immediately checked to a considerable extent, the acceleration due to the fall contending with the resistance of the bank. Each "pocket" excavated (shown by the dotted lines) affords an additional point of attack to the water from above; the load of sediment becoming accumulated and partially distributed as the different fillets, *a*, *b*, *c*, *d*, etc., come in contact with the bank, or with the fillets next the bank, and from the cross and vertical currents arising from the violent disturbance. Finally a point will be reached when the destructive energy is exhausted, the velocity reduced, the angle of presentation of the bank less, and all the conditions favorable to deposition. The load will be thrown down here, forming a shoal. The cross-section will become shallower, therefore wider, and on the whole (the velocity being now at a minimum), enlarged considerably. The slope from *C* to *D* will, therefore, be steepened, and the velocity gradually accelerated, until it again becomes normal, or a little more, at *D*, where the same process will be repeated.

It is evident, then, that the tendency of the river, if unchecked, would be to go on lengthening the bends. This would gradually give a flatter slope to the whole stream, so flat that it would not be compatible with a velocity sufficient to carry the sediment to the sea. There would, therefore, be a deposit in the upper part of the alluvial portion,

and a raising of the flood-plain; and this process would go on indefinitely, assisted by the lengthening of the stream due to the advance of its delta into the sea.

A check is given to this development by two agencies.

First.—The eroding itself cannot proceed beyond a limited extent, for it almost ceases when the bank attacked is at less than a certain angle with the current. If water loaded to its normal capacity flow through straight banks, it will dislodge no more. Neither will it at a gentle angle. In short, it is found by observation that the caving process does not proceed to any considerable extent in ordinary soil and with the ordinary high-water velocity when the radius of curvature of the bend exceeds about two miles.

Second.—The river thus works out for itself a bend which would be circular if the material were homogeneous, and the velocity continued unchanged. It has just been explained why it is not immediately diminished below the normal by impact against the bank—viz., on account of the acceleration due to the fall from the shoal above. But even this acceleration is presently overcome, the velocity is lessened, the curve becomes flatter, erosion ceases, and the current leaves the bank which it has so far hugged, with the direction given by the last reach, to cross over to the other side. If this were not so, the river would speedily return upon itself and form a complete circle. As it is, this tendency is only partially overcome. The river does eventually almost return upon itself until the neck $f\,g$ becomes exceedingly narrow. Sometimes the overpour during high water across the narrowest part of the neck forms a deep gorge on the lower side, which cuts back year by year toward the upper side, after the ordinary manner of cataracts. During some great flood, the velocity of the water, now precipitated across the neck with a fall of perhaps 4 or 5 feet in a thousand, becomes irresistible, and opens a passage for the whole river, thus forming what is called a cut-off.

There is another cause which favors the formation of cut-offs. On account of the continual erosion of the bank and bottom in concave bends, the water becomes very deep, and a cross-section is formed so favorable to the movement of water, that a comparatively small slope is sufficient to give it the velocity requisite. This velocity is at length partially exhausted by the resistance of the curved bank, until finally, in the course of a long and deep bend, the river, even in flood-time, is

approximated to the condition of a pool. Hence, there is a tendency to concentrate the fall into the reaches above and below the pool, so that the slope is alternately greater, less and greater than the mean. Thus the disposition to erosion at both the upper and lower sides of the neck is increased.

So, also, the formation of a quasi-pool in the bend creates a tendency in the water to seek more direct routes. As the river pilots express it, "When a bend becomes very round, the water wants to leave it."

Now, almost all "points" have been formed by successive rudimentary islands, which afterwards grow into perfect islands, become covered with vegetation, and eventually are raised to nearly mean flood-mark. These islands are divided from the main land by channels called "chutes," which are never entirely obliterated, but generally serve as high-water conduits. Frequently, in a bend which has grown very "round," the river will seek such a short cut and make it the main channel, thereby shortening its course several miles. See Plates VII and VIII.

It should be observed that these changes do not occur periodically, or in obedience to any rational demand, so to speak, for compensation. They are local phenomena. Sometimes they happen unseasonably, in advance of any undue lengthening of the river, or when it has already been shortened by other cut-offs. In fact, it has been observed that they frequently occur in cycles, several in succession, where a number of points exist in close proximity, presenting favorable conditions for cut-offs. See Plate IX.

Lest the river should become unduly short by these means, it proceeds to lengthen itself with great rapidity by increased erosion of the bends and building out of the points in the vicinity of the cut-off.

In these ways the disposition of the river to keep on increasing in length is compensated, and the total mean distance from the head of the alluvial basin to the beginning of the delta preserved nearly unaltered, subject only to oscillations. The Mississippi has been observed with accuracy for only a few years, but there is no evidence of any material general elevation of the bed or lengthening of the course since attention has been directed to it.

This sketch of the regimen of the Mississippi implicitly indicates both the nature of the evils which it is desirable to overcome or ameliorate, and the means which lie at the disposal of the engineers for such a purpose.

The principal evils are:

First.—Obstruction of navigation by shoals;
Second.—Injury to alluvial lands by overflow; and
Third.—Destruction of banks by erosion.

I.—The formation of shoals at the nodes or reversion points of bends is assisted by the obliquity of the current to the general direction of the river as it crosses from one bank to the other, thus affording a wider cross-section and a greater frictional resistance.*

Besides these shoals, there are others, which make their appearances principally in reaches which are either straight or of small curvature. These appear to be ascribable to the prolonged fall not now impeded by resistance from bends, resulting in excessive scour, which is now directed against the bottom, and is followed sooner or later by a checking of the velocity in the thread of the stream, and a deposit of silt in the bed below. Where the current and the erosion have been greatest, there will be the greatest fill—viz., in the middle of the stream. This will force the river to divide itself into two branches, and as the form of cross-section is unfavorable to the passage of the discharge, there will be an enlargement of the cross-section. The current being now deflected toward the banks, the enlargement will be at their expense, and the river will assume the appearance of a wide and shallow stream, split in two by a principal shoal or series of shoals, while the material derived from the erosion of the banks goes to form other secondary shoals below. The river is the more ready to shift its channel in straight reaches from the lack of any centrifugal force to hold it against either bank.

Of the two channels, one is frequently used exclusively during high water, the other at low and medium stages; the shorter arm being usually that preferred by the high-water current, according to a principle previously stated.† The channel in use is marked by a rapid current; the "dead end" being almost stagnant; the water level being approximately that of the lower end thereof. In each case, the disused chan-

* Jacquet on the Improvement of the Rhone, page 36. This memoir is published with three others: Janicki on the Improvement of Navigable Rivers; Pasqueau, A Project for the Improvement of the Rhone; and Jacquet on Submerged Spurs; by the Engineer's Department, under the title, Improvement of Non-tidal Rivers. Translated by Colonel Merrill, Washington, 1881.

† *Ante*, page 89. Also noted by Jacquet, page 36.

nel deteriorates until the recurrence of the conditions which bring it into play, when it soon scours itself out again.

Whichever class a shoal under consideration may belong to, the remedy which at once suggests itself is the same—viz., a forced contraction of the width of the cross-section. The result of this will be an immediate rise of the water surface on the shoal. If the bed were stable, a rapid would be thus produced. If it be erodable, the effect will be a scour and a deepening of the channel to an extent commensurate with the contraction.

In a situation similar to that described above, contraction is most easily effected by closing one of the two channels. In other situations, artificial obstacles must be placed in the bed of the stream adjacent to one or the other bank.

All contraction works are modifications or combinations of two systems, that of spur-dikes and that of training-walls. The former are perpendicular or inclined at an abrupt angle to the course of the river, and the latter are parallel or nearly so to that course. There are advantages and disadvantages attached to each of these systems, when exclusively employed, which have often been set forth at length. Many of the drawbacks may be avoided by a judicious combination of both systems.

When circumstances admit, these structures are built of strong and enduring material. On the Mississippi such materials are altogether excluded on account of their expense and their great weight. The bottom of that river is not only friable, it is extremely soft and treacherous, and ponderous structures would soon sink out of sight, unless built on foundations constructed with special care and at immense cost.

Of course, a great part of the skill of an engineer lies in his ability to make use of those materials which are nearest at hand, exist in the greatest abundance, and are most easily worked with such labor as is available. These considerations have led to the adoption of pile-dikes constructed on the permeable system.

By permeable dikes are meant those which are expressly designed not to exclude the water altogether, but to suffer it to pass through them, opposing to that passage, however, a considerable resistance by which a fill is induced. By combining a number of such dikes, systematically arranged, it is designed that an artificial bank shall at length be produced, which will in time grow to the height of the natural, and

whose other dimensions shall correspond substantially to the limits of the system. This is more or less the object of all contraction works, even those of stone.

The plan of permeable dikes presents many advantages on the Mississippi. It economizes material. It uses those articles which are cheapest and most abundant. It is easy of construction and requires little skilled labor. It is light, and remains in position undisturbed, even with the worst foundation. It is by far more effectual than any other in inducing deposits. A standard objection to spur-dikes when of massive construction, has always been the slowness with which they build up the spaces between them. For this reason, the German engineers, the great experimenters with this system, were wont to recommend that spur-dikes should be built, not at once to their full height, but in successive layers, allowing sufficient time to elapse to allow the alluvial deposits of different years to connect with each other.*

The permeable system allows continual access of fresh water heavily loaded with sediment to the interior of the works, thus producing deposits of enormous magnitude, thirty feet or more in depth in places, in a single year.

It must not be forgotten that the closing of a chute by a system of dikes or any artificial narrowing from one side speedily involves encroachment on the opposite bank, unless the latter be protected in some way.

The protection of banks so unstable as those of the Mississippi is a task which may well tax the best powers of the engineer. Nevertheless, it has been attempted with very tolerable success, the results varying somewhat with the methods employed, the difficulties encountered and the workmanship displayed. The greatest difficulties are a swift current, a direct impact, a considerable depth and a very friable material. In what is called "a very bad caving bank," a strong current strikes at an abrupt angle a bank of nearly pure sand. The methods employed for direct protection are, so far, only two—namely, continuous revetment and submerged spurs. They will be described hereafter.

In the works constructed for the improvement of the Mississippi, both spurs and longitudinal dikes are used, combined in systems. The

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* Janicki, page 10. Schlichting on the Improvement of Navigable, Non-tidal Rivers. Translated by Lieutenant Frederick V. Abbot, Corps of Engineers, Willets Point, Battalion Press, New York, 1885.

general principles which have been followed will be learned from the annexed map of the Plum Point Reach.* This is one of the two great "reaches" selected by the Mississippi River Commission for improvement as containing the worst obstructions to navigation on the river, the other being Lake Providence Reach.

The project for the improvement of the Plum Point Reach embraced several distinct operations:

First.—The closing of the chutes between Elmot Bar and the Tennessee shore, by the main and cross dikes at and below Gold Dust.

Second.—The protection of the Arkansas shore from Fletcher's Landing to Elmot.

Third.—The closing of the chutes between the Arkansas shore and Osceola Bars and Bullerton Tow-head, and the protection of the river banks of the latter island.

Fourth.—The encroachment of the Tennessee shore upon the river-bed by main and cross dikes below Plum Point.

Fifth.—The protection of the Arkansas shore below Bullerton Tow-head against further caving.†

The history of these works is highly interesting and instructive, but cannot be given here. They were carried on under many discouragements, the chief being the failure of the appropriations for several successive years. The project has only yet been partially carried out, and last year, for the first time in the history of the work, the discharge of the river, at its lowest stage, was confined to the regulated channel.‡ Yet the last reports inform us of the permanence of the work and the happy results obtained; the least depth of water reported since the inception of the regulation being 8.5 feet, and that only for a few days, where formerly there was frequently only 4.5 to be had.

In the case of the Providence Reach, the work of improvement was complicated by a condition which often exists in the work of river regulation; that is, the presence of a badly caving bank above the reach, the erosion reaching further and further down every year, and threatening perpetual change to the portion of river below, both from the new set which was thus continually given to the current, and from the material which was thus supplied for building new shoals. The

* Plate X.

† Report of Arthur J. Frith, Assistant Engineer, in Report of the Mississippi River Commission for 1884, page 214.

‡ Captain Leach, in Report of Chief of Engineers for 1888, page 2196.

advance of bars or shoals has long been recognized* as a formidable obstacle to regulation, and it is necessary to use some device to prevent it, or it threatens the permanence of the whole system. In this instance, the expedient adopted was the revetment of the caving bank in Louisiana Bend, as it is called. Unfortunately, the work was left without repairs for four years for the want of an appropriation, so most of it has been lost. It will be rebuilt during the coming year. In other respects, the work at Lake Providence Reach was very much of the same character as at Plum Point, and similar results have been obtained.

Both longitudinal and cross dikes are built of several rows of piles, connected with each other by stringers, braces and ties, as shown by the annexed drawing (Plate XI). It may be stated, in this connection, that the first constructions on all these works were on altogether too economical and light a scale, and the materials too perishable. There has been a steady advance toward strength and durability as experience has progressed. Cypress piles are used instead of cottonwood. There are four or five rows of piles where there were formerly one or two. Drift-bolts have been discarded, as tending to split the timbers, and wire fastenings substituted. These latter are of almost universal use in all departments of river work. The wire is annealed and galvanized, and is tightly twisted by a rack-stick. The piles are driven with the assistance of a hydraulic jet.

The bottom of each dike is protected from scour by a "foot-mat" made of brush and poles and weighted by stone in the same manner as the mats for bank revetment. Experience has shown this precaution to be indispensable.

In many cases, the dikes are wattled with brush, to check the current still more effectually. In the earlier stages of the work, inclined screens of wire or brush were used for the same purpose, but I believe they have been abandoned.

The vast "systems" thus constructed at Plum Point and Lake Providence, each covering many square miles, have built up enormous tracts and have fulfilled the essential purposes or which they were designed. But it is found that the interior parts of the system do not progress at the same rate as the outer part. Minor channels and water-

* See Schlichting, page 136.

ways are preserved, which give no little trouble, and cause numerous breaches in the dike, especially the longitudinal, in time of flood. A system like that at Gold Dust (Plate X), connected with the bank at the upper end and joined to an island like Elmot Bar, soon forms a basin with raised margins, which lie along the head and the longitudinal dike, from which at moderate stages the water along the front is altogether excluded, its only means of access being at the foot of the basin. The level of the water in the basin at its head is then lower than that of the river in its front by an amount equal to the fall of the river from the head of the system to the foot of the island. Hence, in time of high water, results a tremendous overfall over the longitudinal dike, which may cause any amount of destruction.*

It has been proposed by Major Ernst, one of the members of the Mississippi River Commission, who has had a great deal of experience on this kind of work, to build the cross-dikes, not to their full length at once, but by successive annual additions, as the area becomes silted up.

The contraction works, as a whole, are successful examples of what may be done in that way; but there are arguments urged against contraction as a principle which are irrespective of the practicability or success of the works themselves. These arguments are mainly two: first, that the material scoured out in consequence of the contraction is deposited below and forms other shoals; and secondly, that the effect of deepening a passage through a bar is invariably to lower the surface of the pool above.

The former of these objections is not a serious one, nor is it necessarily an objection at all. The quantity of earth eroded from a bar to form a V-shaped navigable channel is not very great, nor does it follow that it must be deposited in an inconvenient place. It may be deposited in the pool below, which has an ample, nay, a superfluously great, cross-section. Such is the process usually pursued by the stream in its natural state As the water falls, it cuts out for itself passages through shoals which are generally sufficient for navigable purposes without artificial aid. It must be remembered that the bed is the work of a great river (that is, the river at high water), and designed for its own needs; and a small (that is, a low-water) river is compelled to use it.

* See this lucidly explained in Schlichting, page 164. It has caused a great deal of trouble on the Mississippi.

Hence, the high-water process is to deepen pools and build bars. The low-water process is to scour bars and fill pools.* This process is directly beneficial, as it tends to restore the slope which has been lost in the pools.

The second objection is a grave one. It has been demonstrated that such a consequence is a necessity on theoretical grounds,† and it is abundantly borne out by experience. The effect, of course, of lowering the water surface in the pool above, is to make still shallower water on the shoal at the head of that pool, and thus necessitate correction there. This correction would involve a similar consequence; and it appears at first that this process must continue indefinitely.

In rivers of great slope, like the Rhone, in which the alluvial bed is thin and the permanent strata easily exposed, it is found that the evil above mentioned is very real and serious, and it appears fatal, in such situations, to the system of contraction. On rivers of the type of the Mississippi it loses much of its weight. In the first place, it is found by experience that a lowering of the water surface three or four feet (by a cut-off, for instance, or a crevasse) is hardly perceptible 100 miles above.‡ This is the case even at high water, and is attributed by some engineers to "the small function of the slope which enters all discharge formulas."§ This reasoning does not appear sufficient, nor when tested does it yield a satisfactory result; as a difference of 5 feet in 100 miles should give, in a river like the Mississippi, by Kütter's formula, a difference of velocity of 0.3 to 0.4 foot per second. It would appear rationally ascribable, in part at least, to the disturbances of the flow produced by the resistance of the bends, by which the velocity is brought to a partial check and takes a new start every few miles. Now there are frequently very long stretches of the Mississippi (one, for instance, above Greenville) where there are no shoals which can prove dangerous to navigation for more than that distance. A lowering of the water surface, say, 6 feet, then, at Leland Bar, just below Greenville,

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*See on this a paper by Professor J. B Johnson, in the *Journal of the Association of Engineering Societies* for July, 1884, page 172.

† See Janicki, 13, 18–19; Jacquet, 38–39; Pasqueau, 68 *et seq.*

‡ Humphreys and Abbot, page 397 (Edition 1876) See also the interesting testimony of Captain Leach and General Comstock in the Report of the Senate Committee on the Improvement of the Mississippi River, in 1888, pages 6–7 and 130–132.

§ Extract from Report of Board of Engineers in 1879, quoted in Report of Mississippi River Commission for 1880, page 13; and see Captain Leach's testimony, as above.

would probably have no detrimental effect—in fact, would be imperceptible at Helena, a distance of 175 miles. While it has been shown that a certain lowering of the water-surface must necessarily result, still it does not follow that this lowering is at all commensurate with the deepening of the channel. Such a lowering as 6 feet at any one point is almost impossible, as it would practically annihilate the low water slope, which is only 0.3 foot to the mile.

In the second place, the surface slope which is permitted by the shape of the bed, as formed during high water, is much less already than that demanded by the volume of the river when reduced to low-water dimensions, and can be steepened considerably below without producing serious disturbances for any great distance above.

Thirdly, the partial filling of the deep places in time of low water, aids in divesting them of the character of quasi-pools, and partially restores the slope. The demonstration proceeds, of course, on the supposition that they are actual pools. In reality there is no such thing in the Mississippi, except in the case of a disused channel.

In smaller streams, it has been sought to achieve the end of restoring the slope to the pools by the use of what the German engineers call Grund-schwellen, or submerged spurs, extending from the steep portion of the concave bank which holds the current along the bottom to a sufficient distance, thus constituting a series of sills perpendicular to the current, whereby a deposit is induced. The use of this device seems to have been attended with good results. Its expense precludes its employment in the Mississippi, except in special cases, as a bank protection.

The reasons given above appear to furnish plausible grounds for hoping that contraction in bad spots may not be attended with evil consequences elsewhere. Still, they do not prove that such consequences may not ensue. It is believed that so far there is no evidence of anything but beneficial results on the Mississippi.

II.—For the protection of the bottom-lands from overflow, several expedients have been proposed to confine the principal tributaries by reservoirs at their head-waters, and thus restrain their freshets; to increase the velocity of the river, and hence lower the flood-line by cut-offs; to make a new mouth 100 miles or so above the present one, and diminish the height of the water at that point, and consequently elsewhere; to construct waste-weirs in suitable situations, and let out

the water when necessary; and finally, to build artificial embankments to restrain the flood-waters. Of these, only the last has ever been put into practice to any considerable extent. The rest may be disposed of in few words. Reservoirs, to be of any utility, would have to be on such a gigantic scale as to be impracticable. Even then, they would only restrain the head-waters; and it is said * that the greater part of the flood-waters of great rivers does not drain from the remote mountain-sides, but falls in the valley itself. Cut-offs are sufficiently disposed of by a little reflection upon the regimen of the river. They simply introduce a state of chaos, tearing away and building with wild vehemence, until equilibrium again begins to be restored. A new mouth, higher up than the old, even if it lowered the water surface at that point permanently several feet, would have no material effect 100 or 200 miles above. Lateral outlets or waste-weirs, if large enough to be of any benefit, would be enormously expensive to build and maintain, would work great damage along their course, and would be inefficient, in the long run, for the end proposed. They would both divert the thread of the current laterally, thus checking the velocity, and they would diminish the flowing cross-section below. In other words, they would act in the same manner as crevasses, and cause a fill below them.

This conclusion is not uncontroverted, but is sustained by the vast majority of engineers.

The practice of embanking the lands along the river has grown into a very extensive system, which is rather a series of independent systems. To understand the reasons of this organization, it must be remembered that the Mississippi, like lesser streams, wanders from side to side of its valley, striking the hills which bound it, now on the right, now on the left, and forming coves or basins. These basins are characterized by a general similarity. Each is bounded on the one side by the Mississippi, and on the other by a range of tertiary hills, at the base of which runs the stream which forms the principal drain of the basin. In each, the part next the bank of the Mississippi is the highest, sloping thence to the interior. Each is divided by a great number of subordinate ridges and valleys, with minor water-courses leading directly or through intermediate streams into the grand drain, at a greater or less distance from its mouth. These basins empty their contents respectively through the

* Humphreys and Abbot, page 408.

Saint Francis, the Yazoo, the Red and the Atchafalaya Rivers. All the streams named are tributary to the Mississippi, except the last, which flows directly into the Gulf of Mexico.

The basin first mentioned presents several anomalous features, mainly owing to the extraordinary disturbance which took place there in 1811, due to the famous earthquake of that year. By this convulsion, large portions of the St. Francis Basin suffered a great depression, and are now locally known as the Sunken Lands. The topography of the basin consequently presents some differences from the ordinary alluvial type.

The third in order of enumeration is usually called the Tensas* Basin, from a small stream tributary to Red River, which drains the eastern portion of it. This territory is split up by a considerable number of ridges of pre-alluvial formation.

The "Yazoo Bottom" is almost a perfect specimen of a purely alluvial basin. At its head and foot, the bluffs abut directly on the Mississippi at Memphis and Vicksburg. The hills constituting the eastern boundary form a complete semicircular range, as shown by the accompanying map (Plate XII), which also includes portions of the St. Francis and Tensas Basins.

It is this conformation of the Mississippi Valley which renders it possible and expedient to divide the Levee system into several independent organizations. The peculiar advantages possessed by the Yazoo Basin have long pointed it out for protection by Levees, and the embankments which now guard it are the best specimens of that kind of work. For this reason it is selected as the type for description.

The Levees of the Yazoo Front are joined at their upper end to the hills below Memphis, and continue without interruption to a point a little above the mouth of the Yazoo River, forming an unbroken line of about 300 miles. They are built to grade of 3 feet above the highest known floods, except where they are opposed to a counter-line in Arkansas and Louisiana. In this reach, the grade is raised by degrees to 5 feet above the high water of 1888. The standard form of cross-section is shown in the accompanying sketch. (See Fig. 2.)

The crown or top width is usually 8 feet. The slopes are 1 on 3† on each side, except in special cases. These are, very poor materials;

* Generally pronounced Tensaw.

† So the United States Engineers always express it, and it avoids ambiguity.

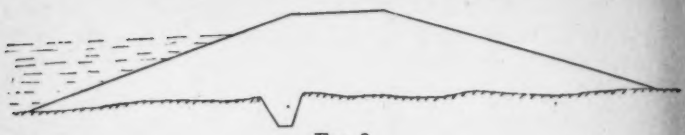

FIG. 2.

great exposure to waves and winds; very bad foundations, and very great size and importance of the work. In the first case, the increased dimensions are given merely for the purpose of strength; in the second, to afford a flatter front slope; in the third, to distribute the weight better; and in the fourth, merely as a larger factor of safety.

There is no formula whereby the proper cross-section of a levee may be determined. In investigations of this nature, it is usually assumed that the forces to be resisted are two: a sliding force, and an overturning couple. This is, of course, on the hypothesis that the structure subjected to these forces may be relied upon to preserve its shape and all its essential qualities unimpaired. Such a supposition is not verified in an earthen embankment long exposed to the continual action of water. It is found that sound levees break principally in four ways. First, from being overtopped by the water, when the overpour completes their destruction. Second, from being cut in two by waves during storms. Third, by gradual disintegration by percolation, causing sloughing on the back slope and eventual disruption. Fourth, from weakness of foundation. If the natural soil on which a levee is built be very light, and if the base of the embankment be narrow, even although the latter be built of the best material, the pressure of the water will often literally force the bottom from beneath the levee, especially if the support be weakened by excavations taken too close; especially on the land side. It is found in practice that the dimensions given above, in ordinary soils, are safe, and that nothing much less is.

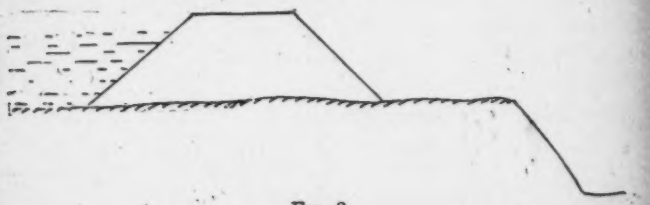

FIG. 3.

PLATE VII
TRANS. AM. SOC. CIV. EN
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STARLING ON
THE MISSISSIPPI R

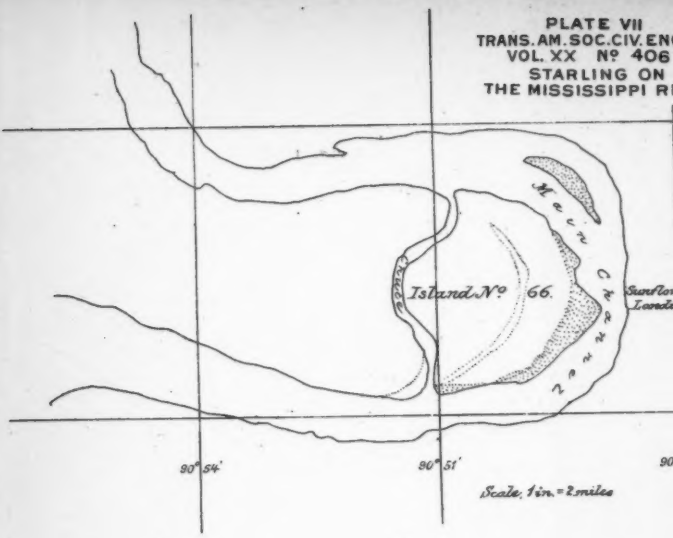

PLATE VII
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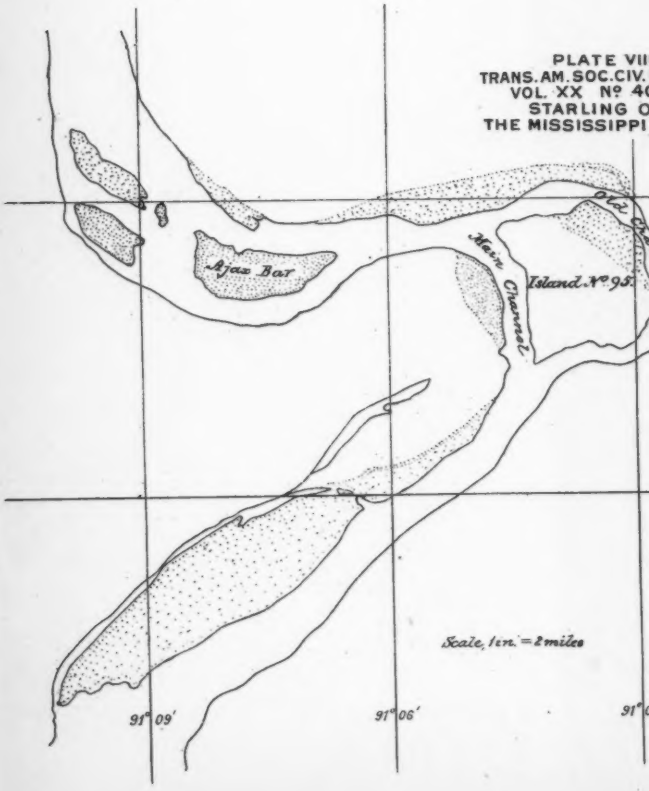
STARLING O
THE MISSISSIPPI



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LATE VIII
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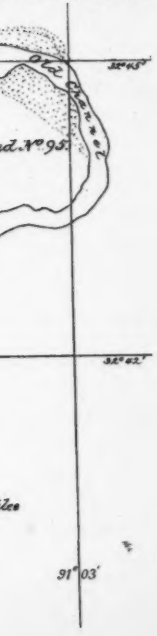
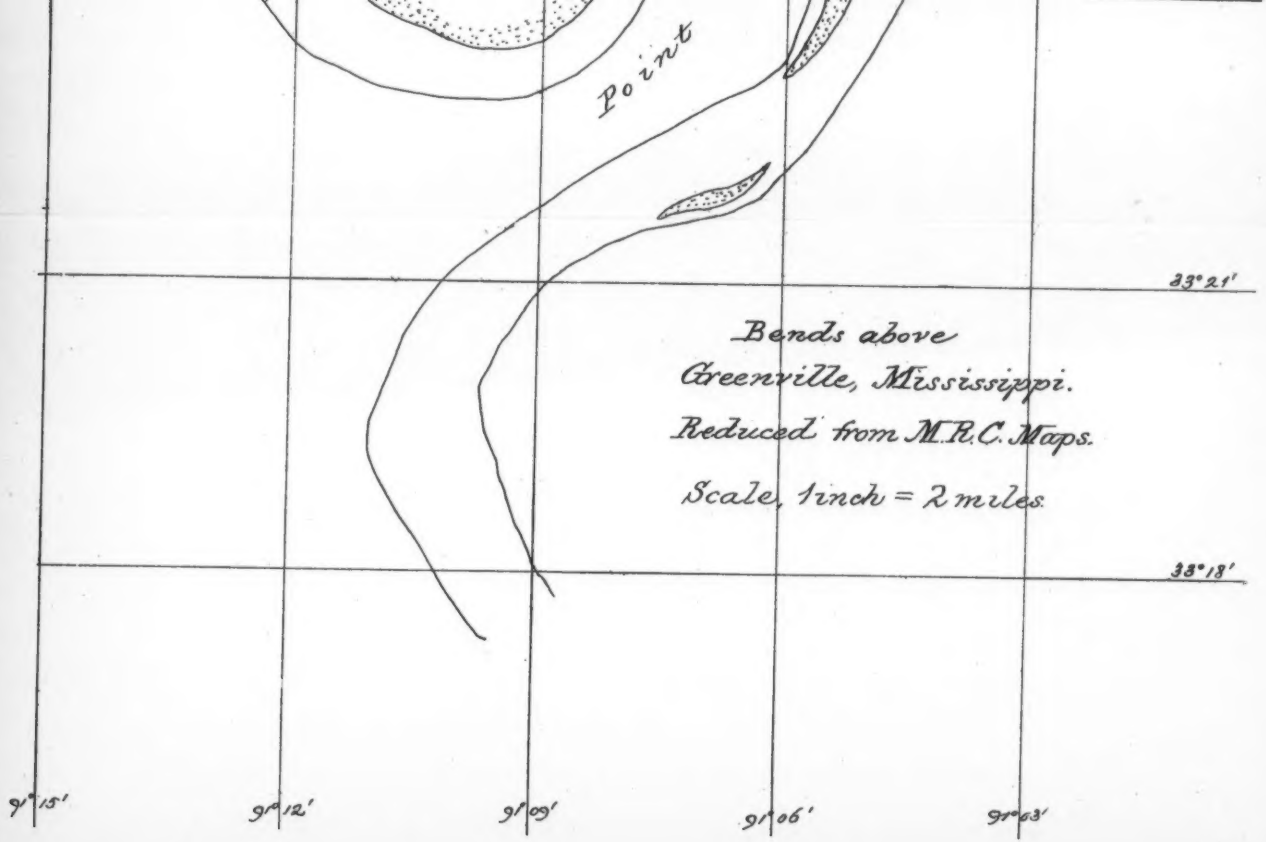
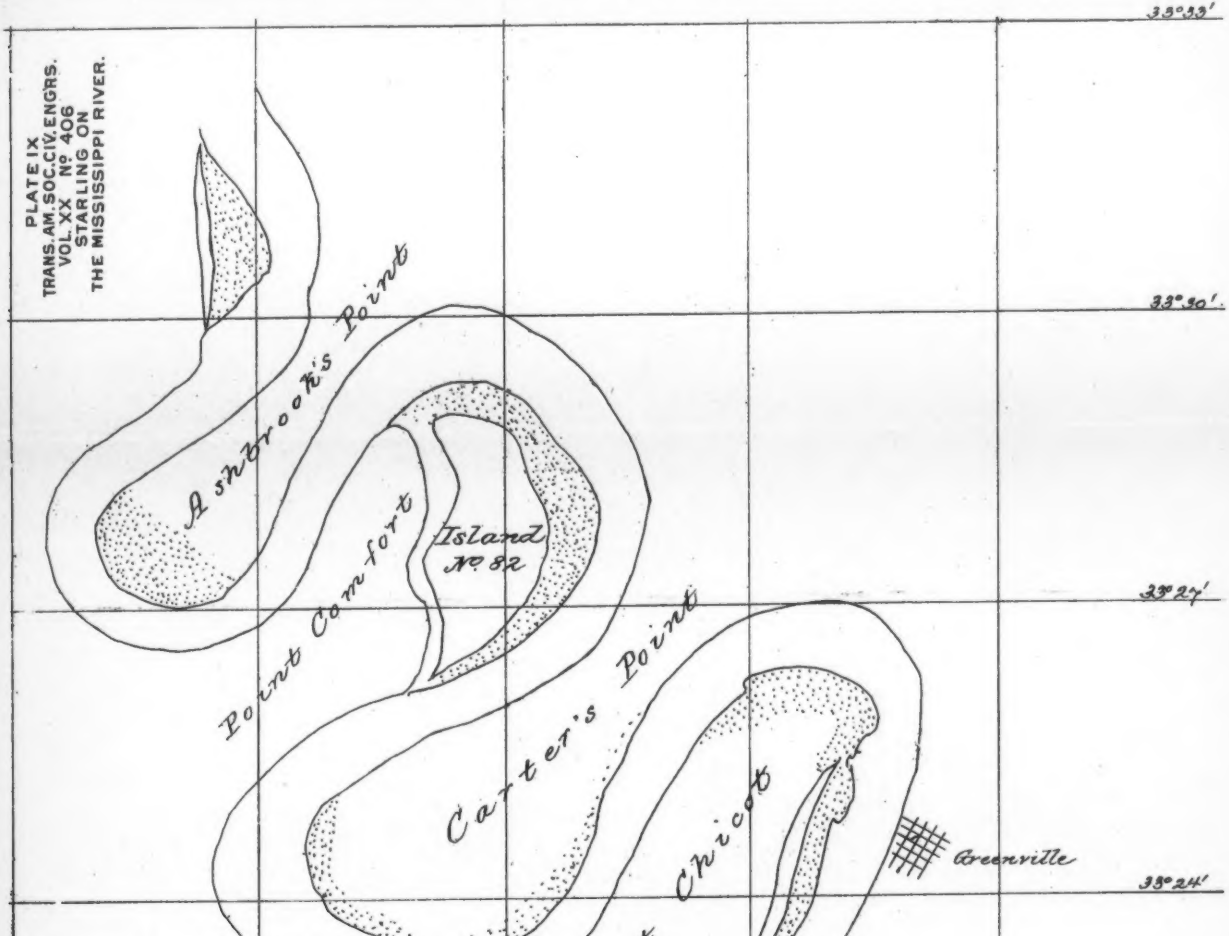
RLING ON
SISSIPPI RIVER.

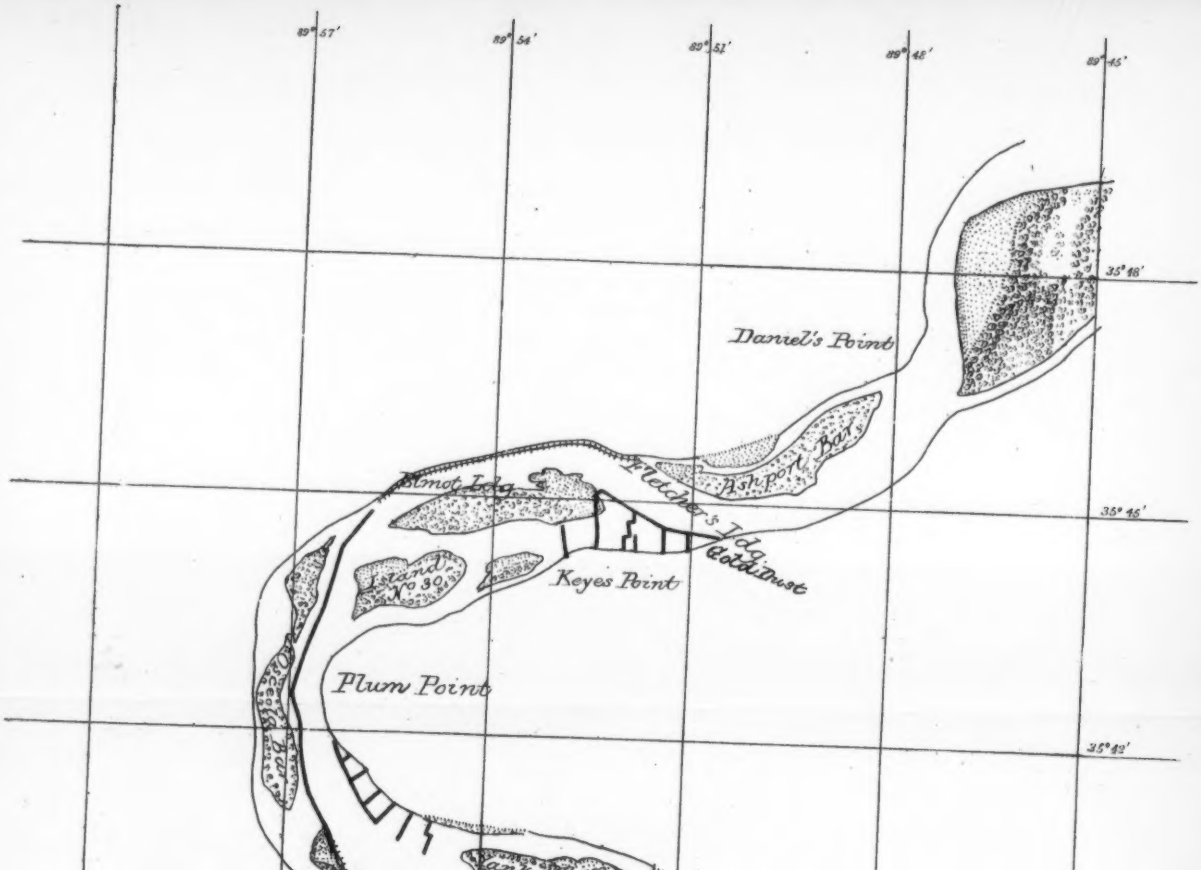




Bends above
Greenville, Mississippi.
Reduced from M.R.C. Maps.
Scale, 1 inch = 2 miles.

PLATE IX
TRANS. AM. SOC. CIV. ENGRS.
VOL. XX No. 406
STARLING ON
THE MISSISSIPPI RIVER.




89° 57'
89° 54'
89° 51'
89° 48'
89° 45'
35° 48'
35° 46'
35° 43'
Darrel's Point
Ashport Bay
Island No 30
Keyes Point
Plum Point

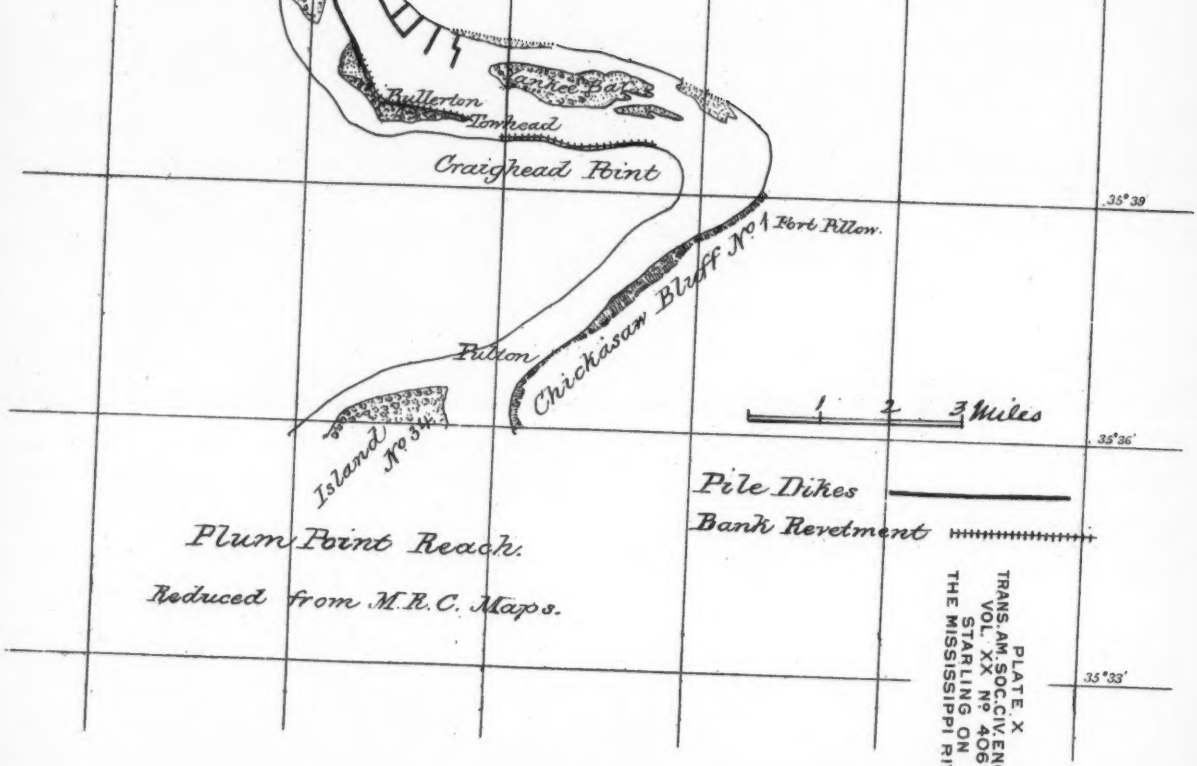
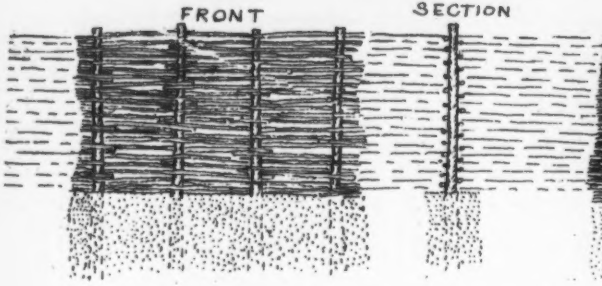


PLATE X
TRANS. AM. SOC. CIV. ENG'RS.
VOL. XX Nº 406
STARLING ON
THE MISSISSIPPI RIVER.

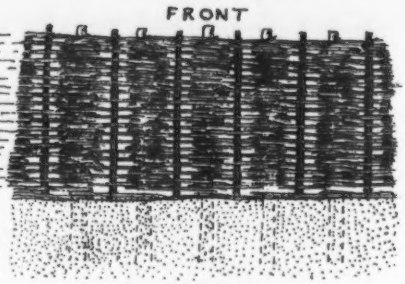
DUNCANSBY SYSTEM.

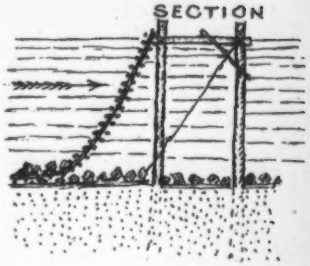
DIKE Nº 1.

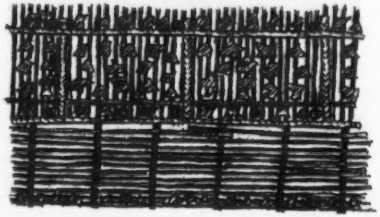


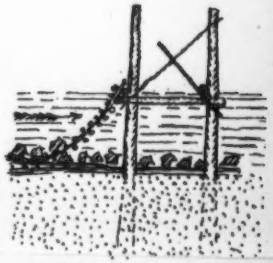
DUNCANSBY SYSTEM

Nº 2.

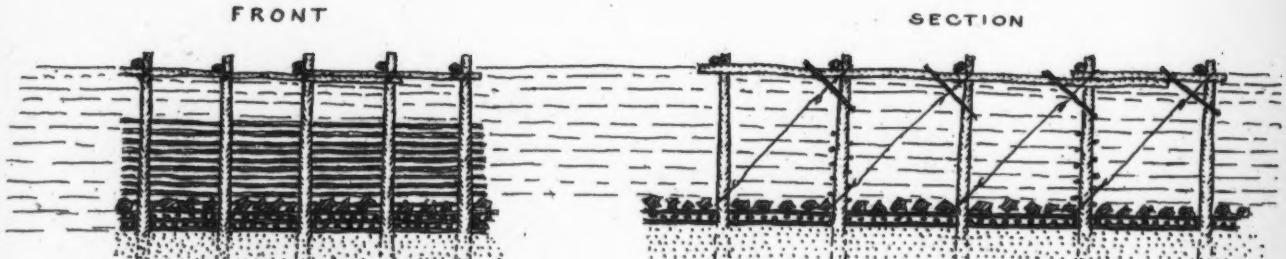








DIKE Nº 4.



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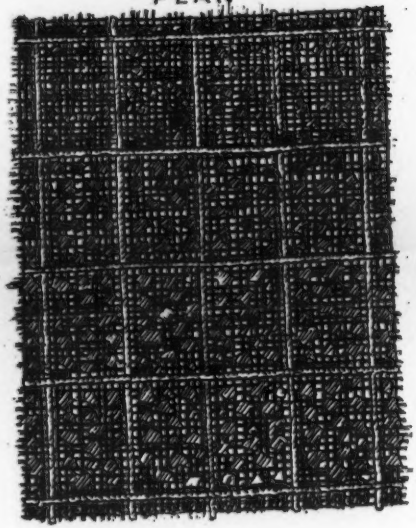
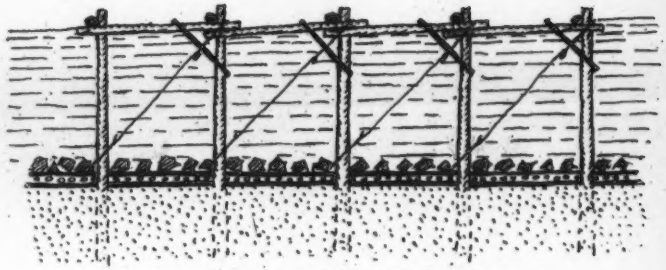


BALESHED SYSTEM

SECTION



Details of Dikes.
Lake Providence Reach.
From Report of M. R. C., 1883.

PLATE XI
TRANS. AM. SOC. CIV. ENGRS.
VOL. XX Nº 406.
STARLING ON
THE MISSISSIPPI RIVER.

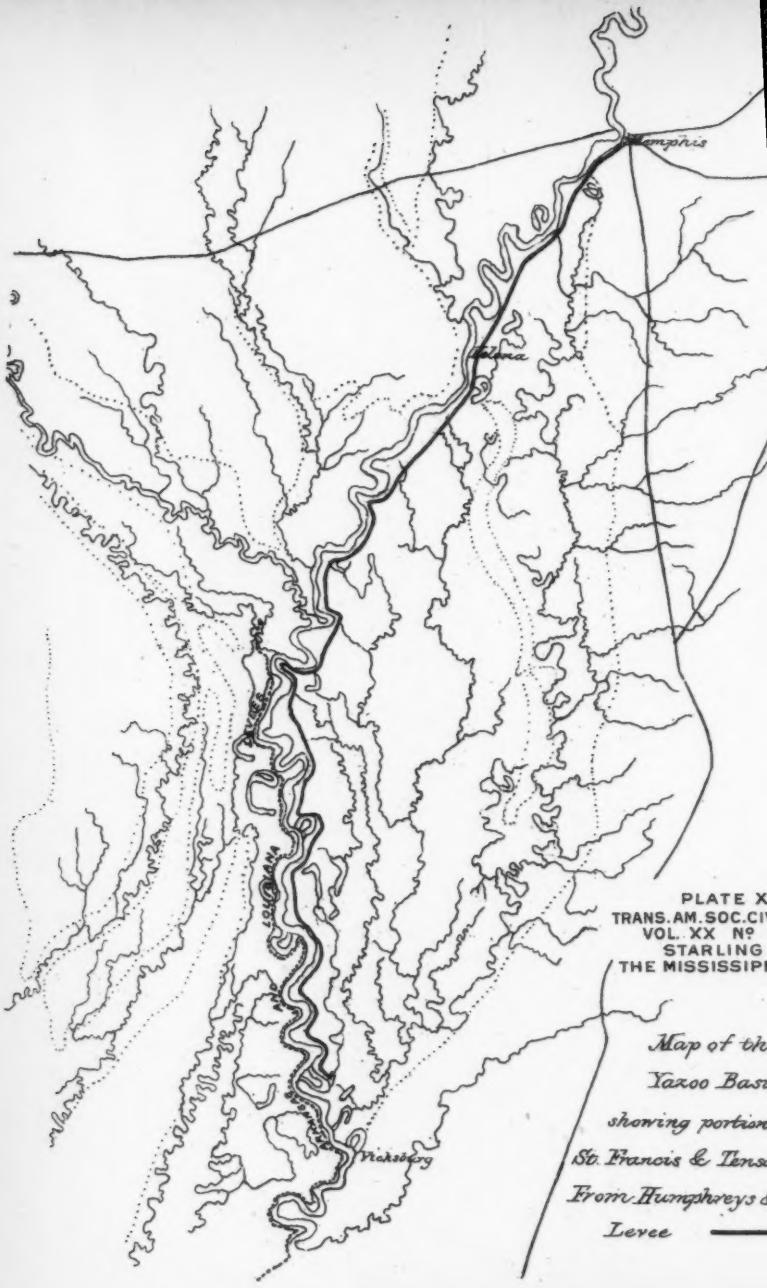


PLATE X
TRANS. AM. SOC. CI
VOL. XX Nº
STARLING
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Map of th
Yazoo Bas
showing portion
St. Francis & Tens
From Humphreys &
Levee

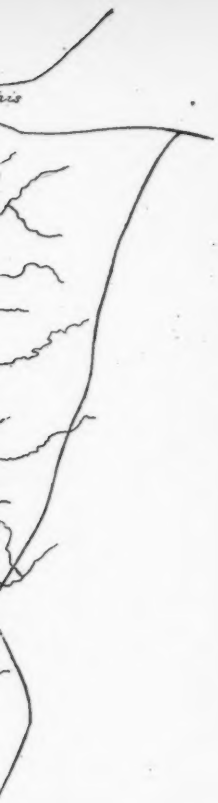

PLATE XII.
AM.SOC.CIV.ENG'RS.
XX Nº 406
TARLING ON
ISSISSIPPI RIVER.

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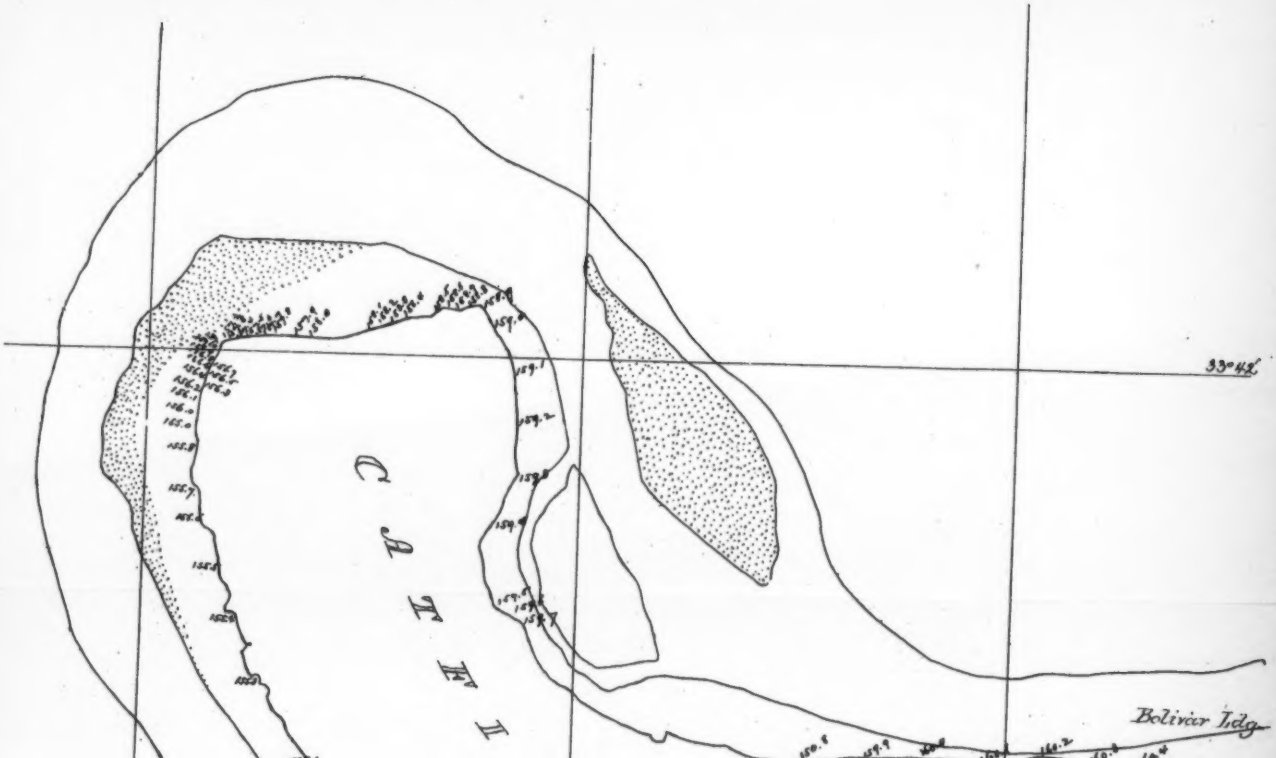
roo Basin,
g portions of the
& Tensas Basins.
ghreys & Abbot.


33°45'
SEATTLE
Bolivar Idg.

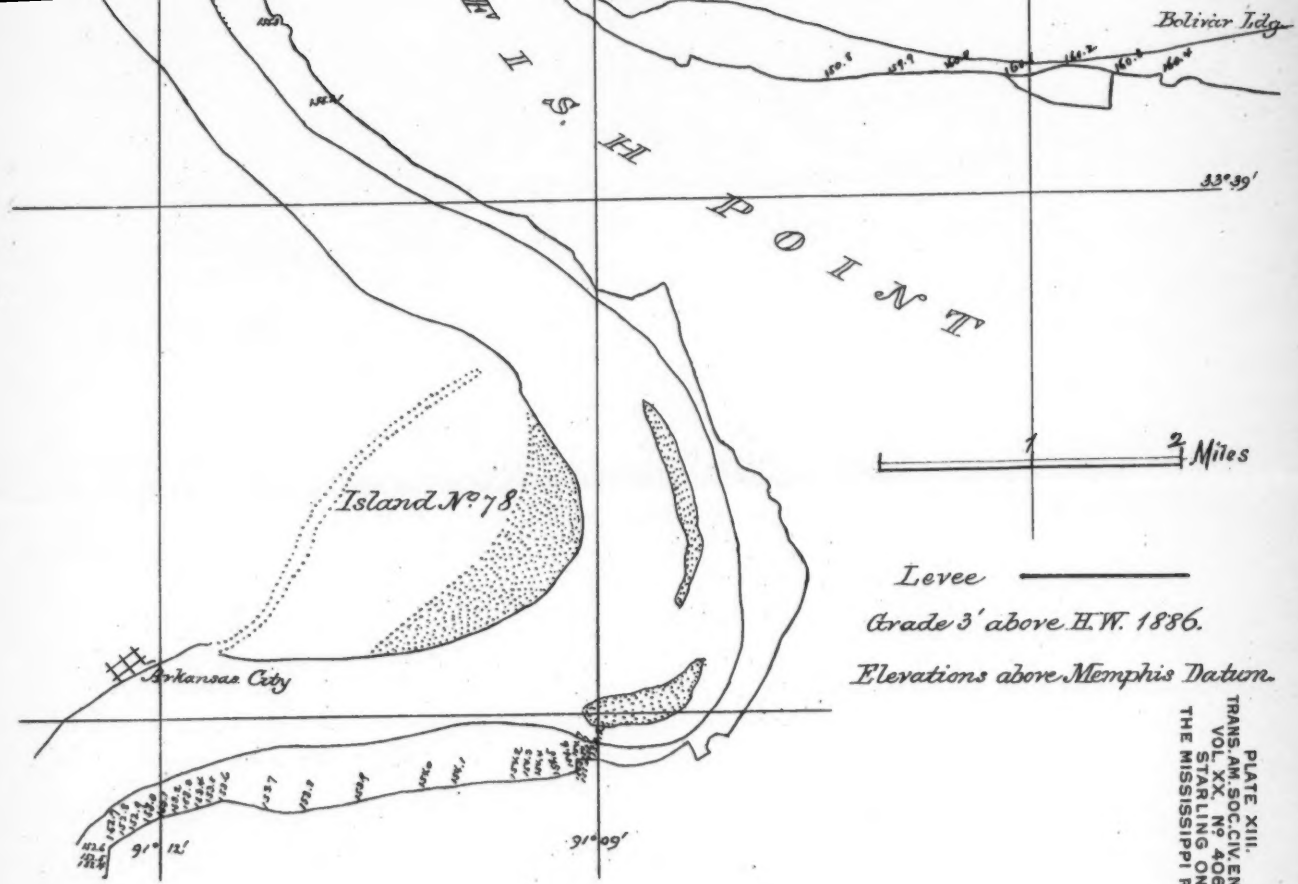
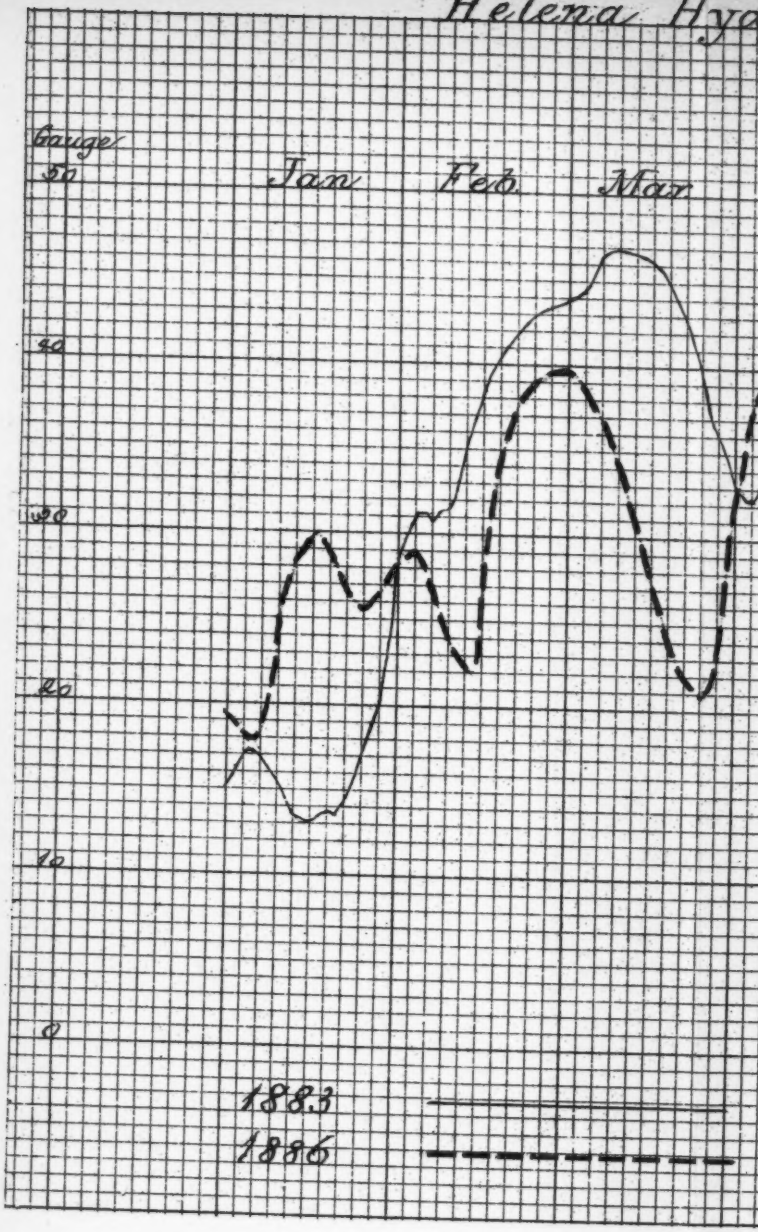
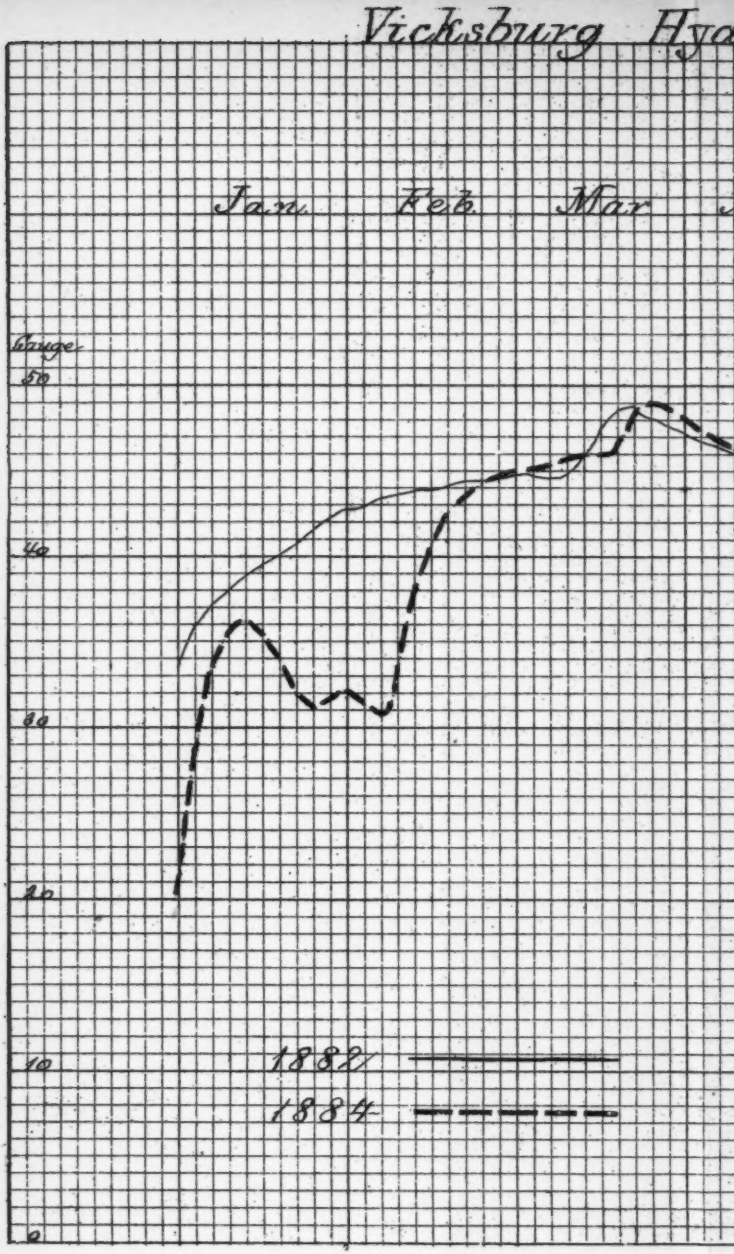
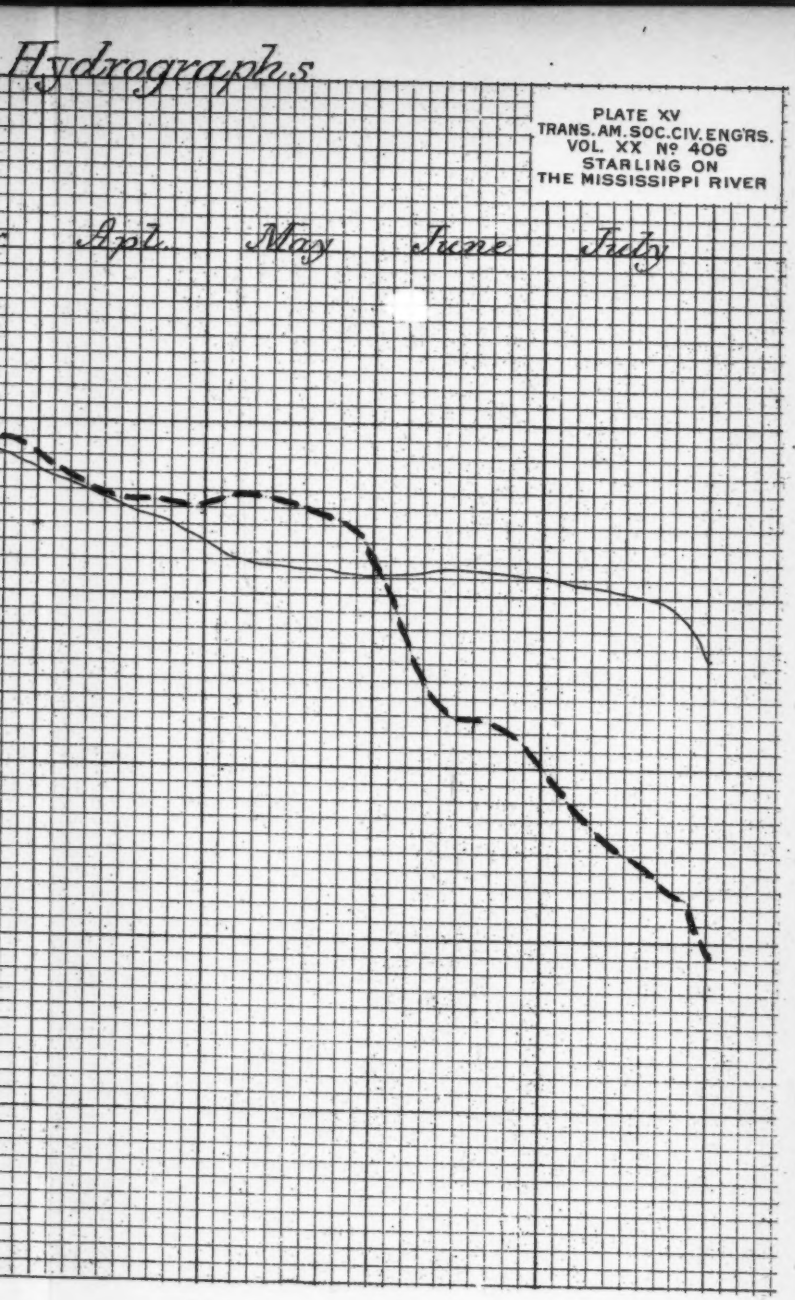


PLATE XIII.
TRANS. AM. SOC. CIV. ENGRS.
VOL. XX. No. 406
STARLING ON
THE MISSISSIPPI RIVER.


Helena Hyd
Gauge
Jan
Feb
Mar
1883
1886

Hydrographs.
PLATE XIV.
TRANS. AM. SOC. CIV. ENGRS.
VOL. XX Nº 406
STARLING ON
THE MISSISSIPPI RIVER.
Apl.
May
June


Vicksburg Hyd
Jan.
Feb.
Mar
Gauge
50
40
30
20
10
0
1882
1884


Hydrographs
PLATE XV
TRANS. AM. SOC. CIV. ENGRS.
VOL. XX Nº 406
STARLING ON
THE MISSISSIPPI RIVER
Apl.
May
June
July

It will be observed that the lower part of the basin is left open. This, of course, is necessary for drainage, but it exposes the lands adjacent to the mouth of the Yazoo to direct overflow, and those a little above to back-water. This damage is not very extensive. The basin is narrow in that vicinity. The slope of the flood-plain is twice as steep as that of the river, being seven or eight tenths of a foot to the mile. The overflow water, then, entering at the lower level of the mouth, cannot mount very high in lands above the mouth. For instance, lands 10 miles above, which would be just awash with the flood-water of the Mississippi in their immediate front, would be 7 feet or more above the back-water.

The grade line of a levee system, of course, has a slope ; but it cannot be assumed for a moment that it should be uniform, so greatly is it modified by the influence of bends, and sometimes by other causes. In exemplification of this Plate XIII shows the grades as fixed by observations of the actual high-water marks, when freed from disturbing causes, of a portion of the levees of the Yazoo front.

The difficulty of establishing grades is much increased when they are to be exposed to influences hitherto untried and only partially known. It was easy to fix the grades of the Mississippi levees when the Arkansas levees were unbuilt. What will be the effect of a complete confinement of the water on both sides? So, again, the flood-line was formerly influenced by the return flow from the crevasses and unleveed lands on the St. Francis and Yazoo fronts. What will be the result of closing those basins? The latter is already completely sealed, the former soon will be.

It is apparent that the best hope for the settlement of these questions lies in a thorough discussion of the discharge observations. Unfortunately these observations are few, scattered, and exposed to various disturbing influences, such as proximity to tributaries and to great crevasses. This subject is of such magnitude and complexity that it cannot be intelligently treated in a small compass. It has been elaborately discussed by Humphreys and Abbot, and by several members and officers of the present Mississippi River Commission, and opinions expressed upon it by many eminent engineers. They are not at all accordant with each other. The grade mentioned above (5 feet above the high water of 1888) was fixed upon by the writer, after a careful examination of all the recent observations, as about the minimum, and was so far approved by the

Mississippi River Commission that they built their levees on this portion of the Yazoo front to that grade.

The element of *scour* is not to be neglected, though involved in much uncertainty both as to the magnitude of its action and the length of time it may take to operate. It is considered as established, from what has been said of the regimen of the river, that the mean high-water slope of the Mississippi is nearly invariable, or subject only to oscillations, and depends on the stability of the soil, being modified locally by natural circumstances incident to such rivers, such as bends. It does not depend on the shape of the bottom, but is itself the cause of that shape; though after forming it, should changes occur in the regimen, it will for a time be more or less constrained by it. When the discharge is lessened by overflow, crevasse or otherwise, the velocity is diminished and the cross-section reduced by the rise of the bottom. When the discharge is restored, by the leveeing of the bank or the closure of the crevasse, the silt accumulated during the reduction is scoured out again. During these operations the slope does not, of course, remain unaltered. While the first process is going on, the slope is steepened at first by the abrupt lowering of the water-surface at the outlet, but its velocity is lessened by the greater friction of the reduced cross-section and by the effect of the cross-current over the bank. Hence the fill, beginning below, but gradually extending. During the second process, the slope is flattened at first, then becomes normal, but its velocity is increased because of the greater volume. Hence scour ensues. This is ordinarily said to be a slower process than fill.* In front of a great comparatively unleveed bottom like that of the St. Francis, or one full of crevasses like the Tensas Basin, which has been in this condition for twenty or thirty years, the accumulation of silt on the bottom is very considerable, and has been consolidated by time. It is, therefore, not easily to be removed. It is said that the elevation of portions of the bottom in front of the St. Francis Basin amounts to several feet. This is no new phenomenon. The tendency of "wild" or unregulated streams to raise their beds has often been noted.†

In the case of the St. Francis and Yazoo fronts, it is hoped that the process of scour will be expedited by means which will presently appear

* Captain Leach's Testimony, as above, page 34.

† See Wex's Second Treatise on the Decrease of Water in Springs, Creeks and Rivers, translated by General Weitzel. Washington, 1881, page 19.

(see page 104). It will, in any event, be much complicated by the fact that a portion of the energy due to the increased velocity will expend itself in the bends against the concave banks. Nevertheless, it is not to be doubted that the cross-section will at length regain its proper dimensions and the slope its normal inclination. The addition of fifty per cent. or more to the volume of the stream—making 1 800 000 or 2 000 000 feet of discharge where lately there was only about 1 200 000—is a change so vast, and involves such unprecedented conditions, that it seems very likely that the forces then to be put in operation may effect great alterations with unexpected celerity.

It is upon these grounds that levees are held by the Mississippi River Commission to be useful adjuncts to the improvement of navigation. It is believed that all the bad reaches lie in places of reduced cross-section. There appears a great probability that the lowering of the bed of the river where it has been abnormally raised will result in a much better shape and greater depth of the low-water channel.

It has been urged against the holding of concave bends in particular cases,* and it applies, of course, to levees in such localities, that they are injurious to the low-water bed, by deepening and enlarging the long pools in the bends, thus concentrating the slopes in the shoals. This is certainly not true in many instances, from the fact already adverted to, that the river, in time of flood, will not follow the concave bends where they are very long and round, but seeks shorter routes. This is well exemplified by a study of the grade line in Plate XIII. It has often been remarked that regions of deep bends are remarkably free from shoals, such as the series of bends shown in Plate IX.

The question as to the closing of the St. Francis and Yazoo fronts is of great interest to levee engineers. Until 1885 the upper portion of the latter front was only partially leveed, and the former has only fragments of levees to this day. In time of flood the water escaped over the banks of both in enormous quantities, and flowed southward until it encountered the hills which bound those basins, when it was suddenly returned through the country adjacent to the mouths of the St. Francis and Yazoo Rivers, raising the flood-line rapidly and enormously for several days in succession. This will be made more evident from an

*Hagen, Memoir on the Construction of the Vistula, etc, translated for the Mississippi River Commission, by Henry Flad.

inspection of the hydrographs of the flood of 1883 and 1886, for Helena, at the mouth of the St. Francis, and of 1882 and 1884 for Vicksburg, at the mouth of the Yazoo. See Plates XIV and XV.

There is not an entire consentaneity among engineers employed in river improvement in this matter, but it is the prevailing opinion that the effect of a complete closure of the St. Francis front would be to reduce this extreme flood-height at Helena. I have never seen the question discussed in print, but the gist of the argument is about this: Consider the case of the Mississippi at flood height, and completely confined by levees from Cairo to Helena. It is then doing its full duty. Now make a huge crevasse, or series of crevasses, in the upper portion of the basin and withdraw say one-sixth of its volume for fifteen days. The discharge will be reduced from 1 800 000 cubic feet per second to 1 500 000. Then the river bed below the crevasse is not doing its full duty for the time specified. Now, suddenly restore the quantity of water abstracted, through the mouth of the St. Francis, at the lower end of the basin, in fifteen days. As the river has been doing less than its duty, so now it will have to do more, and the flood-height will be raised accordingly. It is usually about eleven days from the crest of the rise at Cairo to the highest point of the outflow from the St. Francis, but the abstraction has then been going on for perhaps two or three weeks. The swell from the return flow occupies about fifteen days, but there is sometimes a considerable flow from the basin for a longer period, depending on the magnitude and duration of the flood.

The same reasoning holds good for Vicksburg, at the foot of the Yazoo Basin. It is inferred, on other grounds, that a discharge of 2 000 000 feet (the maximum of the greatest known flood, that of 1882), could be passed at a gauge-height five feet above the high-water mark of 1888. This was 44.2 on the Vicksburg gauge, and would give 49.2 as the maximum to be reached hereafter, against 51.1 in 1862. The evidence, so far as it goes, is not decisive in favor of this opinion, and it has been controverted on other grounds which do not appear weighty. The question, however, is not at all a simple one and needs further investigation.

It is this hoped-for lowering of the flood-line at Helena and Vicksburg which is expected to facilitate the scouring process in front of the St. Francis and Yazoo Basins on the completion of their levee systems. In place of the normal slope above indicated (page 102), as the effect of a

closure of crevasses, there would be a steepening at the lower end which would cause the scour to progress much more rapidly.

Apprehensions have sometimes been expressed that the bed of the river might be raised by levees. This is not possible. If the bed is raised at all it will be in spite of levees, not because of them. Of course, it is perfectly possible, and indeed it is necessary, that in an uncompleted flood-plain (such as presents itself when a river is suddenly diverted from its old bed and compelled to traverse a new plain of flat slope), the process of raising the upper portion thereof should go on until the proper slope is reached. From all accounts, such must be the situation in the case of the Yellow River in China, and in other cases where the embanking of the stream has been attended by a rise of the bed. All that can be said is that the same process would have gone on to a still greater extent had there been no levees.

III.—The third object of improvement has been stated to be the protection of the banks from the inroads of the river, and this not as a mere part of contraction works, but for its own sake.

The chief drawback to the usefulness of the Mississippi in all respects is its instability, and a great portion of this instability is directly due to its caving banks. The reason why there are no great towns along the alluvial banks of the river is that they have no permanent site to stand on. It is from the banks, for the most part, that the material is drawn which goes to form the shoals. It is the lengthening of the bends that induces the conditions favorable to cut-offs; and the cut-offs could not be completed without a continuation of the caving process. Hold the banks and you disembarrass the task of improving the river of its most formidable part.*

The remedy for caving banks must depend, of course, upon the origin of the evil. The cause assigned in a previous portion of this paper—namely, direct impact—is that usually accepted by engineers familiar with river work, but it has not met with universal acquiescence. One eminent dissentient was the late Mr. Eads, who maintained that the whole matter depended upon the degree to which the water was already loaded with sediment. Given a stream with a certain velocity, carrying the quantity of sediment corresponding to that velocity,

* Professor Mitchell early expressed the idea that "the holding of the curves by revetment or otherwise antedates logically the retrenchment which is to deepen the water at the bars." Report of Mississippi River Commission for 1882, page 263.

and it was contended that it could transport no more. Therefore, a bank exposed to the action of such a stream was perfectly safe. It could cave no longer. The reason that banks ordinarily cave in concave bends is, according to this theory, that the water has dropped its load upon the shoal above, and, as it acquires fresh accessions of velocity after leaving the shoal, becomes endowed with an additional capacity for transportation. It can "take up" more solid matter, and this it does until it is saturated, when the process ceases. Hence Mr. Eads proposed to prevent caving in concave bends, or wherever it occurred, by building contraction works on the shoal above. The stream would thus gorge itself with sediment and would be incapable of doing further harm. It is an essential part of this theory that the river is always saturated with the quantity of sediment due to the velocity, the quantity varying with the square of the velocity.*

This doctrine appears to make no allowance for the distance to which the matter may be carried, and yet this appears to be the essence of the whole matter. The whole subject of the suspension of solids in a liquid is little understood. By some it is merely attributed to the effect of parallel and level currents; by others to vertical currents; and it is certainly true that some light matters are held in a state of suspension for an indefinite period in water which is absolutely stagnant. Admitting, however, that there is a normal state of saturation, so called, corresponding, for a given matter, to a given velocity, still this must be understood only on the large scale; such a quantity is all that can be permanently transported for great distances. Take a stream so charged, and throw into it a pound or a ton of the same matter. Will it go straight to the bottom? Not by any means. It will be carried a greater or less distance and eventually dropped. This is actually what consantly occurs on the Mississippi. The water in the grand mean has no more than it can carry to the Gulf. But it temporarily takes up in the bends much more than its proper load, and drops it on the shoals. Furthermore, Mr. Eads' theory takes no account of the sudden changes of direction of the stream, whereby obstacles are abruptly thrown into its path—in other words, of the effect of bends. Yet both reason and observation would assign it an important part.

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* These views of Mr. Eads' have been repeatedly expressed in newspaper articles and pamphlets. I do not know that they exist in a permanent form.

In diametric opposition to Mr. Eads comes Major Powell, who maintains* that the active agent of corrosion, as he calls it, is the sediment already in suspension, acting (as an engineering friend expresses it) like liquid sand-paper. Thus, the more matter the water carries, the more it will dislodge; of course, within certain limits. According to Major Powell, revetment only shifts the evil from one point to another. The true remedy is reservoirs, in the nature of settling basins. The vast majority of engineers believe in actual direct protection of the banks. For some time it was a matter of dispute whether this was practicable, but that question seems to have been settled. There is no higher authority on this point than Captain Leach; and he declares† that work like the Memphis revetment "will certainly protect any alluvial bank on the Mississippi River, no matter how difficult."

Work used for the protection of banks is usually classed under the general head of "revetment," though a distinction may with propriety be made, the term revetment being strictly applicable only to a continuous covering or facing, such as is commonly employed for this purpose. The only other method in vogue at present is that of submerged spurs, which seeks to accomplish the same object by detached works.

Continuous revetment is usually effected by weaving a mattress of poles and brush and sinking it with stone. The mattress is made so wide as to extend beyond the foot of the caving bank, and partly up the opposite slope of the bottom. The work is completed above the water-line by grading away the bank (usually by a hydraulic jet), and covering it with a grillage of similar materials, loaded with stone. It has lately been proposed to use stone alone, without brush, for the upper-bank revetment, and doubtless the experiment will soon be tried.

The submerged spurs are very much like the German Grundschwellen. They are composed of crib-work, and are protected from scour by mattresses 200 feet in breadth under them. The dikes are placed about 450 feet apart. Like the continuous revetment, they extend beyond the foot of the slope of the bank.

Both classes of work are built upon ways, launched as completed, ballasted so as barely to float, then rapidly loaded and sunk. The mats are divided into squares by a top tier of poles, to aid in holding the

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* In Science for August 24th and November, 1888.

† Report of Chief of Engineers for 1888, page 2205.

stone, and the cribs are made in sections, built hopper-shape, each of which forms a weighting-pocket.

The office of the revetment proper is purely conservative. It is intended to hold the bank exactly as it is. The spurs, like the Grundschwellen, are designed to promote a fill between them.

The latter class of works has not yet had a complete trial. They have been used at Memphis, at Greenville and at New Orleans. Under the influence of very rapid currents, there seems to be some tendency to scour between them, due probably to overfall and eddies.

Nothing has been said of the jetties at the mouth of the river, as they hardly come within the scope of this paper. Suffice it to say they are a very successful and beautiful application of the principle of contraction. Information upon the subject is easily accessible.*

It was formerly a favorite notion with the dwellers on the banks of the Mississippi, that it was subject to no laws. Even the most bigoted are now beginning to acknowledge that it differs from other streams only in size, and that science and skill and money will be as effectual for good here as elsewhere.

*Corthell's History of the Jetties, New York, 1881.

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THE IMPROVEMENT OF CHANNELS IN SEDIMENTARY RIVERS.

By GEORGE H. HENSHAW.

WITH DISCUSSION.

Of all engineering works for the purpose of intercommunication between peoples, perhaps the earliest are those of a hydrological character. Not to speak of the ancient canals of Egypt, Babylon, etc., we have the more modern example of a whole country reclaimed from the sea and made accessible by inland navigation, as in the case of Holland. Following this feat came the era of canals, which has lasted down to the present generation, during which the invention of railroads and their astonishing multiplication has entirely eclipsed these slower modes of transportation, or at least reduced them to the position of regulators of commerce.

The possession of navigable rivers, however, is still justly regarded as a most important factor in the prosperity of a country, and this is practically proved by the fact that the towns situated at the head of navigation remain always larger and more prosperous than other inland centers in spite of railroad enterprise elsewhere, though no doubt they retain their place through the full share of railroad communication which they naturally attract.

Of course the reason of this superiority lies in the fact that goods coming by sea are brought further into the country without transshipment.

Unfortunately, many of the largest of these great arterial channels of communication run through soils of an alluvial character, and are therefore much hindered in their course by shallows and obstructions, as well as by bars formed at their mouths by the sediment they have borne into the sea; the mode of dealing with the latter difficulty having only recently been demonstrated, in the case of the Mississippi River, by the successful enterprise of a distinguished natural genius. Up to that time attempts of the kind had been deemed too hazardous to venture upon, and the main efforts of commercial enterprise were directed towards railway connection with those ports whose natural advantages enabled them to accommodate vessels of tonnage suitable to the requirements of modern traffic.

The Mississippi (which is here taken for the purpose of illustration) was too important a stream, forming as it does with its tributaries the natural outlet of a large number of the Western States, to be neglected by the United States Government, and for a number of years efforts have been making to remove shoals and other obstructions and improve its navigation.

Justly to appreciate the difficulties attending these efforts a short physical retrospect of this river may, though familiar to many, be permitted.

Whether human eye ever rested on the first formation of the Mississippi River, we cannot tell; neither history nor tradition nor geology throw any light upon that point; but geology does tell us that at one time its whole region was a sea, extending from the Gulf of Mexico to the Arctic Ocean and down the St. Lawrence Valley to the Atlantic, making the northern part of Canada one island, and the New England, Eastern and Middle States another, or more probably an archipelago. The upheaval of the northern portion of this area caused, first, the appearance of the great lakes and the St. Lawrence, while a continuance of the same movement gradually, at low water, defined the position of the Mississippi system, which might be seen cutting its way through the diluvium left by the retreating sea, being bounded on either side by vast areas of low, marshy ground. At high water, however, these marshes would be covered by an expanse of water, deposit-

ing upon them the sediment brought down in suspension. The effect of this would be to raise a broad belt of sediment on each side of the main current, so that at last the river would occupy the axis of a ridge instead of a valley, which indeed is actually the case.

Of course, in obedience to a universal law, the river would become tortuous; but the principal effect which concerns us is, that a stream which thus forms its own barriers, tends to widen its borders by frequently changing its channel under a law which compels it to seek lines of least resistance, rather than to remain in one channel, and, by so doing, induce a scour which would secure a depth throughout competent to establish a safe and permanent navigation. One other result of this formation may be noted in passing. Under the varying conditions of its creation, whether on account of cosmic elevation or the excavation of its bed, or both combined, parts of the river in flood time are held within its banks, while others, less favorably conditioned, have their natural banks overflowed, making necessary the construction of artificial "levees" to keep in the water.

Now, bearing in mind that the object sought is to secure a permanently navigable channel, it is plain that merely protecting the banks or bluffs from erosion can have no effect beyond preventing a certain amount of sediment being added to that already encumbering the stream; the old varying conditions still exist over the spacious bottom, and in some way these must be altered.

To do this effectively but two methods seem possible, each distinct from the other in principle. They have, however, a common ground in the acknowledged proposition, that an ideal river is one whose banks are coincident with the sides of its channel, and whose cross-section is competent to inclose its flood water.

Broadly stated, the first method consists in the use of either solid dams or barriers permeable to water extending from the shore to the channel, for the double purpose of directing the latter into its desired course and accumulating sediment at its sides. The result looked for is a contraction of the river bed to the required limits, but the following objections may be urged against this plan:

First.—That structures of the kind, whether solid or permeable, present direct opposition to the natural flow of the stream, their height and area of obstruction being the measure of their resistance and consequent liability to be undermined and destroyed. Besides this, their elevation

above the bottom exposes them proportionally to destruction from trees, snags and other floating "drift."

Second.—That in case these structures are destroyed, the large local accumulations of sediment which they cause are thrown upon the lower river, seriously endangering its channel. It must always be hazardous to introduce artificial conditions strongly in contrast with the existing natural conditions.

Third.—That an attempt to obviate the danger by simultaneously improving a great length of channel by this means would be extremely difficult on account of the great labor and cost, and, if carried on at different points, it has been found that even where locally successful, the obstruction removed has often been transferred to unimproved points lower down the river.

Fourth.—That the conditions of the river being so variable that no general rules can be devised which can in all cases be applied, the success of these structures in one place is no criterion for their success in others; a fact which has been amply and practically proved by the experience of those engaged in the work.

Fifth.—That the principle itself involved in these structures is defective, since it is an attempt in the direction of forming the ideal river directly the reverse to the process by which ideal rivers are naturally formed. The ideal river, where naturally found, is not formed by building up its own banks; it cuts its way through a refractory formation. It deepens rather than widens, because, under the law of movement in lines of least resistance, it can bring the forces of velocity and depth against the bottom, while lateral friction is all it can bring against the sides.

The second method, which is the main subject of this paper, makes no attempt to accumulate sediment. Its object is to supply artificially to the bottom, on each side of the desired channel, that element of resistance to erosion which is essential to the ideal river; and it relies upon the action of the inevitable law just mentioned to scour out the channel and continue to do so, to a depth only limited by the slope of the river, or by encountering a stratum that cannot be naturally eroded. By this means it is expected that the ideal river will shape itself under a strictly natural process, for it will be seen that the artificial aid introduced acts solely in supplying a natural deficiency.

The device, the principle of which has just been given, consists of a loose-woven, permeable fence, made of the lightest and most flexible material, such as osier willow and the like. This is first laid in a continuous line with the channel, at a distance from each side of it to be fixed according to circumstances—as a rule, about 300 feet. This line is connected at the up-stream end, and at other places where needed, with the shore by similar fence strips, while others are run out in a series of spurs to the edge of the desired channel. The arrangement is shown diagrammatically in Fig. 1 of the accompanying sketch (Plate XVI). Figs. 2 to 5 are details of the device. The strips are made in sections 8 to 10 feet long or more, which are fastened together in such a way as to allow the whole when laid down to follow the curvatures of the bottom.

Fig. 2 is the base of one of these sections. It is an open frame of 2 x 2 inch scantling, with cross-pieces at convenient distances apart. Four strong wires, two on each side of the center line and fastened by staples, are for holding the upright fence, the mode of securing which is shown in section Fig. 5. Fig. 3 is a side elevation, showing its light and permeable character. Fig. 4 shows the end section of the fence at the edge of the channel. It is triangular, being of full height at its attachment to the next section, and diminishes to nothing at the other, forming a slope of 3 or 4 to 1. This is done to reduce the resistance at the channel edge to a minimum. It is well known that water flowing past an obstacle burrows downward or undermines in proportion to the height and cross-sectional area of the obstructed flow; but this point will be further noticed when the operation of the device is described.

Slabs of clay are used as ballast in sinking the fence to its position. They are placed along the center before wattling, or upon the base, at each side of the upright fence (see Fig. 5, Plate XVI). Clay is preferred to stone because it brings the center of gravity lower and because it will keep its place securely while launching.

The fence is about 3 feet high, the height assumed to be best for the purposes intended. Its structure is calculated to accumulate sediment, but only to the extent of covering its base and anchoring it firmly, while its great flexibility gives it when partially silted up a permanent set down-stream. Its regular construction and even top line is intended to spread the sediment affected by it smoothly over the bottom of the river.

Fig. 6 is a diagram cross-section, showing the operation of the device under the least favorable conditions—namely, where the channel has been shoaled across, forming a bar which must be cut through.

The continuous line is the bottom before operations have begun. The cross-hatched line is the fencing strip, and the dotted line the effect produced upon the channel and its sides through the law which compels it to seek the line of least resistance. The accumulation of sediment shown, thrown off laterally by the relatively greater speed of the channel current is an action which, while it cannot be theoretically disputed, is also practically proved, not only by the fact that the river itself flows upon an elevation of its own making, but that the jetties at its mouth were backed up by sediment flowing over each layer of the mattresses as fast as it was laid. It is scarcely necessary to cite other cases.

In an unconfined channel, if able to maintain itself, the tendency under the "least resistance" law is of course to deepen most in the middle; but where it is confined this tendency is neutralized more or less, and even overcome, according to the character of the barrier confining it. A solid wing dam or a range of piling will cause the water to burrow down close to the obstruction, if it cannot undermine it, and thus bring the deepest part to the side. Less and less formidable obstructions will produce less and less effect, and for this reason the spur ends have been formed to produce the least possible resistance. Still, it cannot be denied that even their slight resistance will cause some tendency to undermine, and this is provided for by the short sections into which the strips are divided, the end one sinking into the depression and making the protection even more effective than before. It may possibly, indeed, be found of advantage to form the base of this section of iron rods, so as to accommodate itself more promptly to this action.

Supplementary Structures.

Figs. 7 and 8 have nothing to do with the main object above described, and though important, are supplementary rather than essential.

Fig. 7 represents a strip or fence similar to that above described, but modified to serve the special purpose of filling up depressions and so bringing the area outside the channel proper as near as may be to a level. The vertical fence is therefore made of stouter and less flexible

brush work, and its top line is cut in such a way that, when laid, it will become horizontal at a few inches above the sides of the depression. It is, of course, only intended to collect sediment; but though necessarily exposed to injury from floating objects, this danger is greatly reduced, both by its not rising above the general level, and by its loose form of plaiting or wattling, which allows such objects to tear their way through by forcing the meshes apart without doing much damage. Its total destruction even would be a small matter compared with the loss of a solid dam or other structure usually employed.

It is to be noticed that all the fences used under this system are carefully made so that their elasticity may be nearly uniform, also that their tops are cut to a regular line. This, as is stated in the description of the channel strips, is in order to produce an even sedimentary deposit over the bottom. Sediment is not brought into suspension in proportion to the velocity of the stream, though that may be the cause of the cause; the real cause is agitation. Water, therefore, flowing over sediment lying in heaps and ridges, will, at the same speed, raise and carry off more than if it passed over a smoother surface. Hence, by the means proposed more deposit will take place and less sediment be carried away than by any other device at present known.

Fig. 8 represents a protection to the banks at places where the current impinges upon the shore at less than a certain angle (salient or more directly exposed points are best protected by the kind of mattress work at present in use). The brow of the bank is trenched to the top on the line of the slope and the top edge of the barrier is cut to a slope of 3 or 4 to 1. It may be secured to the bottom by stones or stakes and the foot further protected by fascines; the intention of course is, by the collection of sediment to fill up the irregularities of the shore line and reduce it to a regular sweep.

It will be seen that by the system here advocated, the ideal river will form itself in a natural manner—that is, by deepening between refractory bounds—while at the same time the sediment thrown off at its sides is building up its banks. How much, or how little, this deposit may be, is a matter of no importance to the preservation of the channel. Its chief value will lie in the eventual reclamation of land.

It is true that in high water there will probably occur frequent attempts of the river to leave the channel and cross the shoals; but as soon as it wears down to the buried fencing strips, the incipient channel

will glide over their inclined meshes, and being unable to go deeper, will widen, divide and finally become obliterated. Of course, should it be found advisable to fix the sediment and prevent this action, where a considerable amount has been superimposed, this can be done by laying down another range of strips similar to the first, making the boundaries of the channel still more impervious.

DISCUSSION.

William P. Craighill, M. Am. Soc. C. E.—There seems to be a tendency to undervalue canals at the present time. Is this wise or proper? It is true that some canals have ceased to be useful, but it is equally true that some railroads have never paid financially. A canal or a railroad which is injudiciously located relative to natural lines of trade will probably never pay. So, also, the direction and character of a line of trade may change, and the usefulness of a certain canal or railway be thereby greatly diminished or entirely destroyed. Some other canals have been very useful in spite of bad management and political misuse, and others now closed would pay but for these and other causes. Canals are decried by the great railroad interests and by the newspapers controlled by them. The reasons are very obvious. A canal tow-path or bed makes an excellent and cheap ready-graded road-bed for a railroad.

There is an inter-relation between the several means of internal transportation—viz., smaller canals, ship canals, railways and rivers—which should not be lost sight of. In a newly settled or very thinly settled country the main dependence must be placed on the natural water-courses for heavy transportation. As population increases and the country is developed, railways are built, and for a time they can do all the business required, thus apparently superseding water transportation altogether; but as the wealth and density of populations still farther increase, the necessity of transportation by water, by rivers and canals, again becomes manifest. That this is true is shown by what is now going on in several of the states of Europe.

It may be freely admitted that for passenger traffic the day of the canal is past, unless it be for such people as the Irishman who requested to be permitted to work his passage on the canal by walking on the tow-path and driving the horses. But the cheapness of the canal for the movement of bulky or heavy freights which will bear slow movement to a market, will always be recognized. The day may come when the business of transportation of passengers will be entirely separated from the movement of freight, and great lines will be given up entirely to

IMPROVEMENT OF CHANNELS IN SEDIMENTARY RIVERS.

Fig 1. Diagram.

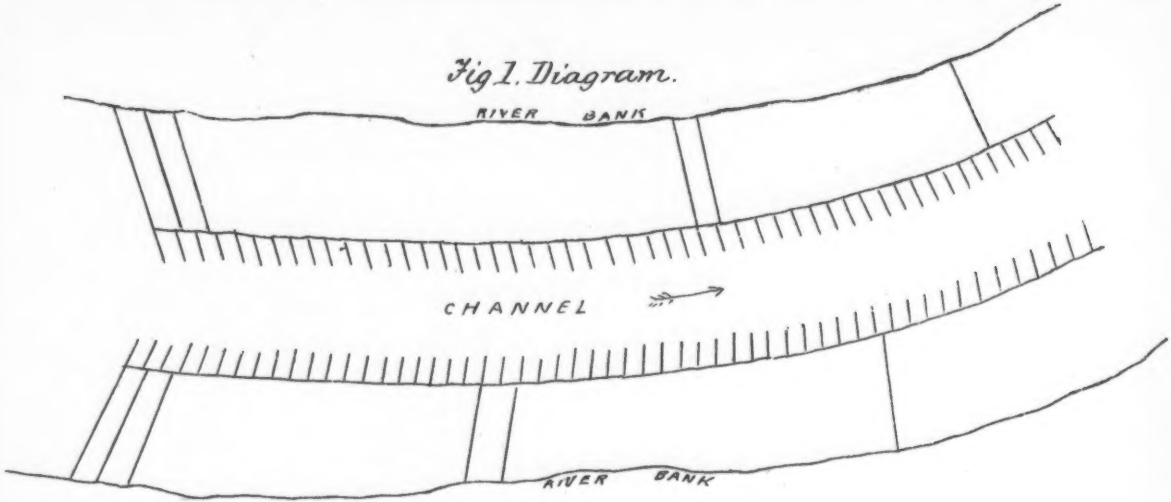


Fig 2. Base.

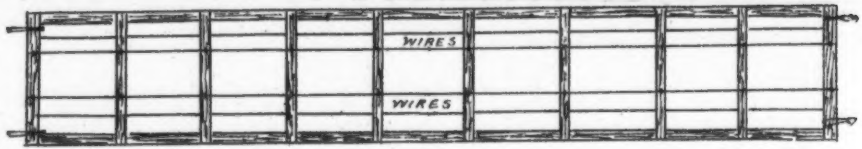


Fig 3

Fig. 5.

Fig 4

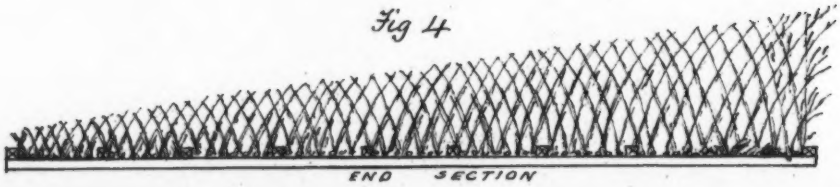
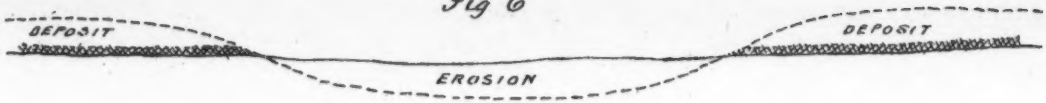


Fig 6



Supplementary Structures.

Fig. 7.

Fig. 8.

PLATE XVI
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the latter work. If, in addition, those roads be so managed that every man may put his own car on them and have it carried on equitable terms, another revolution in the methods of freighting may be seen.

In this connection it would be extremely interesting and profitable to refer to the remarks on the subject of canals by Mr. T. C. KEEFER, Past President Am. Soc. C. E., retiring President of the Canadian Society of Civil Engineers, in his recent address. He gives us the benefit of his own experience and observation with canals, two things which make him a most competent teacher.

It is very doubtful whether the means proposed by the author for the improvement of the Mississippi River would accomplish all that he expects or give any really useful or permanent results.

The proposition to build dikes of light and flexible material, such as brush or wattling, is not a new one. Such dikes were in use in our own country on the Missouri River for a number of years, trials having there been made of various forms of "weeds," "willow curtains," "wire screens," etc. The credit for the dike of "weeds" is given to Colonel Brownlow of the Royal Engineers, and a description of it may be found in "Professional Papers on Indian Engineering," April, 1875. See also Annual Reports of Chief of Engineers, U. S. Army, 1879, Part I, page 654; 1879, Part II, pages 1050 and 1075–76; 1880, Part II, page 1452.

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CLAMP FOR PULLING SHEET PILING.

By CHARLES E. EMERY, M. Am. Soc. C. E.

The trenches of the New York Steam Company vary from 4½ to 6 feet in width and from 5 to 8 and 10 feet deep. In the lower part of the city most of the soil is sandy, and although some of the fills are hard pan, the continual use of the streets and passage of heavy trucks alongside the trenches necessitates sheet piling the sides quite closely to prevent the caving of the banks. In sand or any loose material close piling is always resorted to. The piling used is spruce plank 10 feet long, 10 inches wide and 2 inches thick. It is driven down with a wooden maul, slightly in advance or closely following the excavation, according to the nature of the soil.

It was at first the practice to pull the plank as the filling was put in, but it was finally decided to allow the plank to remain in place until the fill was completed, then to pull each plank separately, sift sand in the hole and ram it with a thin, wide tamping bar, continuing this operation until the hole was filled; then to pull the next plank and proceed as before.

During the earlier work of the company, the foreman had constructed, for the purpose of pulling these planks, plain rectangles of bar iron, with an eye on one of the sides connecting to links with which a

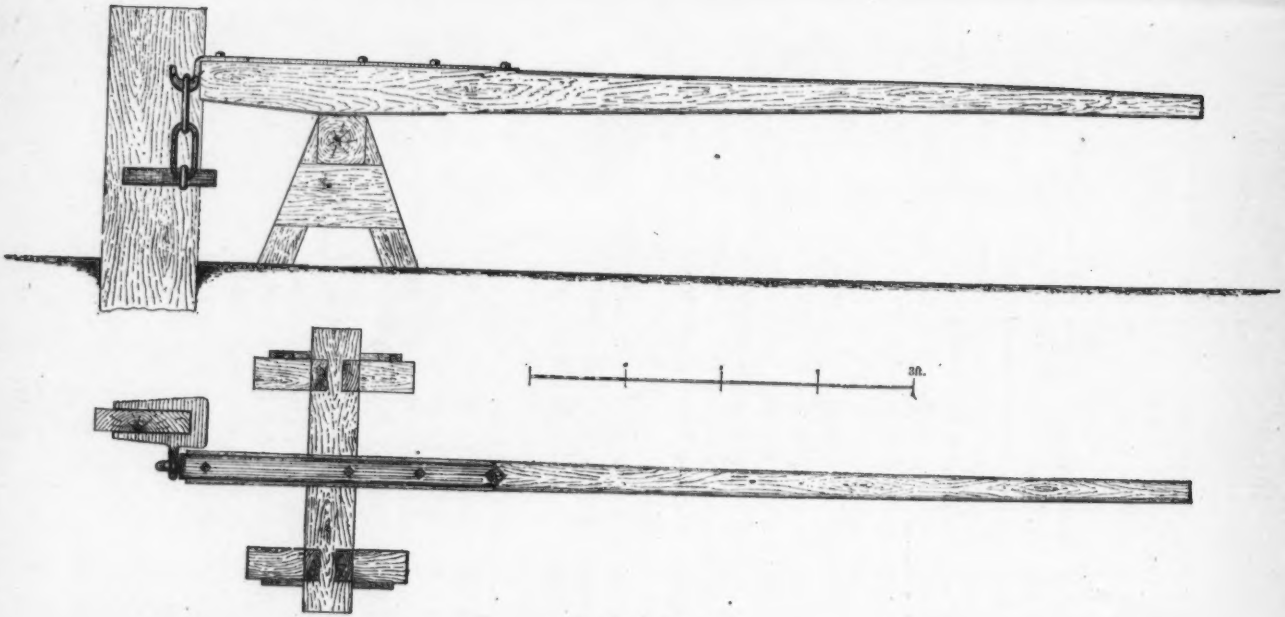

PLATE XVII.

hook on the pulling lever engaged. The connecting eye being at one side, the clamp was tilted as it was lifted, so that its edges engaged with the soft wood with sufficient grip to enable the plank to be pulled. The use of this instrument, however, required that the end plank of close sheet piling be pried laterally sufficiently to admit the end of the clamp, an operation requiring some delay and annoyance. To overcome this difficulty, the writer designed the clamp shown in the accompanying Plate No. XVII, which, as will be seen, is a mere fork of iron with interior parallel sides to fit loosely the sides of a plank and extend from one edge to nearly its entire width. The back and rear sides of the fork are thickened to stiffen the open jaw. An eye is forged on one of the sides, a little nearer the back than the points of the jaws, so that the head and points nearly balance, and to this eye is connected a pair of links, as shown. A heavy wooden lever, iron bound, with hook to engage with the links and a heavy horse to form a fulcrum, complete the outfit. In practice, the clamp is slipped on the edge of the endmost plank and the lever simply worked up and down ; the clamp loosens itself and falls down as the lever is raised and binds as the lever is depressed. Sometimes five or six men are on the lever at once to start a plank buried 6 or 8 feet in the earth. The sizes shown are those which have been developed by the practical members of the force after several years' trial.

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DESTRUCTION OF RAILS BY EXCESSIVE WEIGHTS.

By JOSEPH T. DODGE, M. Am. Soc. C. E.

WITH DISCUSSION.

In the Report of the Committee presented at this Convention,* there are carefully engraved diagrams of the cross-sections of sixteen pairs of rails, much worn by use. The sections were taken with a view of shedding light upon the proper radius for the corners of rail-head and the flange fillet of wheels.

The significance of the diagrams for the purpose intended is very marked, but they convey a lesson of still more definite import in another respect. They show conclusively the flow of the metal of the rails under the excessive weights constantly passing over them.

On the rails of a fast-speed tangent no lip is perceptible on either rail, but on like rails for slow speed the lip is clearly visible. On the rails of a fast-speed curve, there is a heavy lip on the outside of the inner rail, and only a very slight one on the outside of the outer rail.

On a slow-speed curve the lip upon the outer rail is more marked, and on the inner rail a little less so than on the fast-speed curve.

These facts harmonize with what is to be seen in almost any railroad yard, the speed being slow and the destruction of rails by the flow of metal something enormous.

* Report of Committee on Relation of Sections of Railway Wheels and Rails, Vol. XIX, page 1, July, 1888.

They also clearly indicate that wheels carrying excessive weight may pass harmlessly over rails at high speed, like a boy skating over thin ice, when at slow speed they would be very destructive.

It has been argued that because in a certain experiment where a pressure of 53 760 pounds per square inch was applied to a piece of soft iron by a steel die ½ inch square before producing a perceptible indentation, therefore an engine or car-wheel on a steel rail cannot produce any distortion of fiber. Now, argument is good in its place, but it cannot controvert the facts before our eyes.

That the metal of the rails flows under the weight of the wheels is a fact of observation. That those weights are excessive is a conclusion of reason.

No form of rail can be devised which will insure any definite area of bearing for each engine wheel or each car wheel. These bearing areas will vary as the radii of the wheels. They should also vary as the width of the rail heads. They will vary also according to the condition of the tires, some being flat and some made concave by wear. Car wheels are usually curved; drivers are not; hence by no possibility will all the wheels of a train have the same contact with any one rail.

The conclusions deducible from the foregoing appear to be as follows: diameters of wheels should be as large as practicable; rail-heads should be as wide as practicable; tires should be kept as flat and perfect as practicable.

As to the diameters of the wheels, the area of contact of wheel with rail being directly as the diameters, the weights to be carried should decrease in like ratio.

If 15 000 pounds is a permissible weight for..... 5-foot wheel,
then 12 000 pounds would be an equivalent load for... 4-foot "
9 000 " " " " " " 3-foot "
8 250 " " " " " " 33-inch "

Hence an eight-wheel freight car weighing 25 000 pounds, when loaded with 41 000 pounds additional will be fully as destructive to the rails as a Consolidation Locomotive carrying 96 000 pounds on its eight drivers of 4 feet diameter. Switch engines, having large loads upon small wheels, prove very destructive to rails, as may be seen in almost any city.

In view of the facts just stated, the tendency to increase the weight of rolling stock seems to me to have passed its proper limits and that we should call a halt.

DISCUSSION.

W. W. RICH, M. Am. Soc. C. E.—Mr. Dodge suggests that I discuss this subject. I have made no preparation to do so, but in conversation with him, I have learned his views and expressed my concurrence. The subject is one of much interest, and I will say this:

Last year we modified the specifications of our freight cars (Minneapolis, St. Paul and Sault Ste. Marie Ry.), bringing them up from 40 000 to 50 000 pounds capacity, and we have had about one thousand cars constructed on these specifications. I now consider that it was a mistake. If I had it to do over again I think I would not make cars—certainly not for general traffic—to exceed 40 000 pounds capacity.

The Master Car Builders' Association recently appointed a committee to determine the proper sized axle for a 60 000-pound car. It seems to me that that committee ought to be discharged before they have time to report. So far as my observation goes, a car loaded to that limit has too great a weight per wheel load for the surface of the rails. I know of a railway company in Wisconsin that has tried some 60 000-pound ore cars, and the Superintendent tells me they are for sale cheap.

I have no statistics at hand, but my recollection is that Mr. Octave Chanute, M. Am. Soc. C. E., once made some experiments to determine the actual area of contact between rails and wheels of various sizes under loads, and that for 33-inch wheels such area was about one-tenth or one-eleventh of a square inch. For an eight-wheel car weighing about 27 000 and carrying 50 000 pounds this would give a pressure per square inch of about 100 000 pounds, which is much beyond the elastic limit of the metal in our steel rails. That "flowing" under such pressure should occur, would seem inevitable.

Being responsible for the freight equipment and locomotives adopted for use upon our line, I thought I had given proper attention to wheel loads, but think now that an error was made in the matter of freight cars.

As to driving wheels of engines, I think we kept fairly within the limit, with 13 750 pounds on a 64-inch wheel; but a switch engine with 16 000 pounds on a 52-inch wheel leaves its record about the yard in some good sized steel splinters rolled from the rail heads; but the pressure here per square inch is but little greater than for 33-inch wheels under a fully loaded 50 000-pound car. We know that the tendency is continually towards heavier cars. Must we not give more attention to the relation of wheel loads to the bearing surfaces of rails?

On the one hand is the question of the earlier renewal of rails, extra cost of heavier cars, and cost of hauling the additional weight of same when empty or not fully loaded; and on the other hand, the old question of percentage of dead load to paying load, which the narrow gauge

agitation justly brought into prominence, and which is now the groundwork of every argument in favor of cars of still greater capacity. Where is the economical limit? Except for special traffic, such as coal, ore, etc., it is not probable that one-fourth the large cars in general service carry loads averaging so much as 40 000 pounds each. Box cars of 50,000 and 60 000 pounds capacity weigh from 2 000 to 3 000 pounds more than 40 000 pound cars, and consequently by increased dead weight, unless they are fully loaded, diminish the revenue obtainable from the use of a given motive power. The only compensating advantage is in the reduced cost for repairs, or the longer life of the heavier car.

THOMAS RODD, M. Am. Soc. C. E.—As of interest in this connection, in an examination recently made with reference to railway bridges, I made some inquiries of operating officials, and found that the actual car loads are often very much higher than either gentleman has spoken of, both as to single cars and whole trains. I know also of some cases on roads where long coal trains are hauled, particularly the Baltimore and Ohio. I cannot say from memory just what the weights of the cars are, but an idea of it will be had from the fact that the gross weight comes to very nearly 4 000 pounds per lineal foot. The facts were published in the *Railway Gazette* some time during last year.

Upon the roads with which I am connected there are a certain number of cars (about 50) of 80 000 marked capacity. They are for special service, but have been moved over the entire line. These cars will weigh about 120 000 gross, and I know of an instance where more than 300 000 pounds net load was loaded on three of them; they are about 30 feet long and have twelve wheels under each; they are generally used in special service, but are often moved over the line with iron ore.

As to the flow of material in rails, that has been observed by all engineers familiar with the operation of railways, and it no doubt occurs in the way Mr. Dodge has stated. I think, however, that this flow has not been confined to recent years; it has existed since I have had knowledge of these matters. In the earlier days—my earlier days—sixteen or seventeen years ago, I observed this flow frequently, especially on the outside rails on curves.

The sections mentioned by Mr. Dodge were taken at my instance for the use of a Committee of this Society, whose preliminary report has in it some reference to this flow of metal. There is no question that the flow does occur to some extent, and has always been present under heavy traffic.

Engineers to-day, especially those dealing with the construction and maintenance of railways, have to face the question of how best to provide for heavy engines and heavy loads. In the sixteen or seventeen years I spoke of this question of loads has been constantly brought up.

No year has passed that I have not heard discussions as to why operating officials constantly increase loads, thereby placing upon railway structures a more severe service than that for which they had been most carefully designed. These discussions have not had the slightest effect. The loads have been increased, and they will, in all probability, be still further increased. They have come up from the 10-ton car load of some sixteen years ago to the 30-ton car load of to-day. Freight cars are being improved in every way; patent couplers and air-brakes are coming into use, and the cost of cars will be largely increased. It follows that they must be made to do more work and carry more load; we know very well that an increase in freight car capacity must be followed by an increase in the hauling power and consequent weight of the engines. I take it that we have to provide for actual loadings—not for the present loads only, but for greater loads than the present; and I feel sure that any effort to reduce the loads would be futile. Engineers could not, even should they wish to do so, stand in the way of progress in railway transportation. For myself, I feel sure that, as regards our track and bridge superstructure, we should take a bold step forward, and provide for an inevitable future increase of loads.

In the past our structures have become disabled before they have given a reasonable service, partly for the reason that, in designing them, we have used the then present loads, on the insufficient ground that we had arrived at the maximum weights of cars and engines. I believe that we have no more ground to assume this to-day than we had at any time in the last twenty years, and that it is better for the structure to be made stronger than is required for the present needs, than that it should be overtaken and found too light in a few years; in other words, it is a practical question whether we have not been remiss, often, no doubt, for urgent economical reasons, in providing weights just sufficient for the present needs, instead of realizing what must come in the near future, and providing for it.

What I say here refers more particularly to our railway bridges, but to a large extent it is true of our rails and other track materials. As to the bridges, the old expression of "factor of safety" has been largely dropped, but practically we do design our bridges with a certain fixed margin for safety. What I would like to see done would be that bridges should be designed more with reference to a factor of endurance. On heavy traffic lines iron bridges have had to be renewed generally because the heavy service and increasing loads have found them to be too light, either in special parts or in general. When we consider the large amount of money invested in railway bridges, it certainly seems to me that they ought to give longer life and better service; and, if only for that reason, I am in favor of taking a decided step forward, and giving them ample strength to resist the wear and tear, besides providing a margin for future increase of loads.

PERCIVAL ROBERTS, Jr., M. Am. Soc. C. E.—I am not myself a railroad man, but one who uses railroad cars. In connection with this discussion, we speak of the capacity of cars, but I think the railroads do not take into consideration the manner in which these cars have necessarily to be loaded. They are capable of holding their rated loads when uniformly distributed, yet those cars are very often loaded so that a much greater weight comes on certain wheels. I had occasion recently to load cars of 40 000 pounds capacity with heavy girders which extended over several cars, and which necessarily had to be carried at two points only to allow the cars to swing from under when passing around curves. The cars were loaded much below their rated capacity, say 20 000 pounds per car, and they were unable to sustain the load. So great a settlement took place that the girders had to be removed.

F. W. SKINNER, M. Am. Soc. C. E.—Is it not the general practice to distribute the load by suitable blocking, so as to throw it ultimately onto four or more points directly over the trucks? I have loaded, and seen many plate-girders, up to 80 feet long, supported on slipping plates at two points, one near each end, to enable it to ride around curves, and these points, supported by cross-blocking, distributing the loads among two to eight points on the car floor.

Mr. ROBERTS.—No, I do not think so. You cannot get enough money from the railroad companies to put up expensive false works. The strain comes largely upon one point in each car.

A. GOTTLIEB, M. Am. Soc. C. E.—In my experience I have known of parties taking every proper care to load long, heavy pieces so that the load shall be properly distributed over parts of the car over trucks. Mr. Skinner suggested two points of support from which to distribute the weight over all the cars by blocking. I had occasion to load some long pieces recently which went over three cars; the center car had no load at all, the two outside cars had the load properly distributed.

The railroad companies have experienced men who inspect a car at every point, and, if the cars are not properly loaded, or if there is any danger from loading, they certainly refuse to take them out.

Mr. ROBERTS.—Does Mr. Gottlieb mean to say that where a car is loaded the entire weight is borne by both trucks, uniformly distributed?

Mr. GOTTLIEB.—I do not say it is, but it can be made so.

Mr. ROBERTS.—I think the best method is to have a car which will carry the load. I would be glad to know of its construction.

OBERLIN SMITH, M. Am. Soc. C. E.—It seems to me difficult for a very long girder to be blocked securely over a train of several cars, with the ordinary blocking, on account of the vertical irregularities of the train and the swaying of the cars sidewise at different points. But I think false works may be built without much expense, by making a timber framing over the truck of each car, which would be elastic in

itself, by having under it enough ordinary car-springs to bear the required weight. By this means the girder would be distributed all over the train, and the jolting of the cars would be relieved to a great extent. Of course some of the timbers bolted under the girder must slide freely upon timbers attached to the car, to allow for lateral motion in traversing curves. The car springs could be merely borrowed for the occasion and much of the timber could be afterwards utilized.

Mr. SKINNER.—The expense is small, especially when old ties are used, as is frequent. In this connection the methods of shipment of the arch segments of the Harlem Bridge may be interesting from its novelty. The maximum size of the pieces was about 18 x 11 feet x 20 inches wide, weighing 14 tons. Gondola cars were used, in the floors of which longitudinal slots about 20 feet long and 30 inches wide were cut. Through this slot the girder section was suspended, with its lower flange a few inches above the ties, by A-braces at each end bearing on underside of top chord flange, and bolted to 10 or 12-inch transverse horizontal channels fastened to the end of the section and the sides of the car. Inclined end braces gave longitudinal steadiness. About twenty cars were thus fitted, and sufficed to transport all the pieces, over four hundred. The arrangement worked satisfactorily and no complaint was made of the expense.

MENDES COHEN, M. Am. Soc. C. E.—I only want to say a few words on this subject. The question is a general one; it concerns the increase in weight of rolling stock generally.

There is no doubt that cars have been increased in weight within the last fifteen or twenty years. The increased life and strength of our road-beds, due to the general use of steel rails and improved joints, have made it possible for lines of heavy traffic to increase the weight and power of their locomotives.

On some of these lines, particularly those of high curvature, and on others where light grades prevail, economy is found in concentrating the loads into shorter trains than the increased power of the engines would permit to be hauled with the old car equipment. Hence came the increased weight and capacity of the cars. So long as these cars, which appertain mostly to main or trunk lines, are only hauled upon the lines for which they were devised, no especial inconvenience is complained of from the increased weight per wheel. But as soon as they diverge from these lines onto less important roads, whose road-beds are less substantially built, the trouble begins, and the rails and road-beds generally are found to suffer under the excessive wheel loads.

There is no remedy for this except in the gradual improvement of the road-beds of the outlying lines.

There will be in the future, as there always has been in the past, a constant struggle between Track and Load, which will only terminate

when we arrive at a standard weight and section of rail, which may not be further modified without unfavorably affecting its economical employment.

I think, therefore, it is entirely useless to look for a present remedy to suffering road-beds in a reduction in the weight of cars. The lines which have found the increased capacity of their equipment both necessary and economical will make no change in this direction, and it only remains for those who feel the burthen to come gradually up to the standard.

The Special Committee of the Society now considering the relation to each other of the Sections of Railway Wheels and Rails may, and it is hoped will, throw light on this question in its report.

D. J. Whittemore, Past President Am. Soc. C. E.—In this increased weight of the rail, from 56 to 66 or 70 pounds to the yard, has the quality of the material been kept up? On the line with which I am connected we have a rail of 65 or 70 pounds to the yard, that, when new, will stand less traffic than one of 56 or 57, made under the same specifications as the former. Does not this imply that as the mass is increased, more thorough working of the material, in the process of manufacture, is required?

James B. Francis, Past President Am. Soc. C. E.—I suppose this question of flow is a case of exceeding the elastic strength of the metal. By this I mean a strain, so that the metal does not return after the load is lifted. The remedy would be to reduce the strain; there is no other way to accomplish it. I don't see that it depends upon the strength of the rail, but upon the strain that is applied to the upper point in the rail. If the strain there is beyond the elastic limit this flow will take place.

Max J. Becker, M. Am. Soc. C. E.—It seems to me that there ought to be no difficulty in providing a rail capable of resisting the force which is said to cause a flow in the metal. The trouble is, that the increase in the carrying capacity of the rail has not been kept up in the same ratio with the loads imposed. In the earlier fifties the general weight of rail was about 50 pounds per yard. At that time the freight cars carried 10 tons, the locomotives weighed 20 or 25 tons. To-day we are carrying 30 tons in our cars and our engines weigh 60 tons, which shows an increase of 300 per cent. in the loads. At the same time, the largest rail sections in this country now rarely exceed 74 pounds, so that the increase in the sectional area of the rail would be about 50 per cent., while the loads have been fully trebled. This is disproportionate. When you remember that the head of the rail has been but very little increased in bearing surface, you will readily see the utter disproportion between the provision made for carrying and the amounts to be carried.

Still, I am not prepared to accept Mr. Dodge's theory, that any considerable portion of rail failure is due to the yielding or flowing of the metal under the large concentrated wheel loads. Is it not more likely that the effect observed by Mr. Dodge is caused by the sliding of wheels while passing over the rails with brakes set?

It is the general opinion of observing railroad men that the increased speed of the trains, added to the greater weight—in other words, the increased momentum—causes the destruction of the metal in the rails. If this opinion is wrong, have we not been at fault in making the large customary allowances for impact in computing the members of our bridge structures?

J. T. DODGE, M. Am. Soc. C. E.—I think Mr. Francis has presented the real point. The difficulty is not that the rail is not strong enough now to carry this load from tie to tie, but that the surface of the rail is not strong enough to support the weight which disturbs the fiber. The elasticity of the rail is overcome and the metal takes a set, it simply flows. Widening the head of the rail will not be a sufficient remedy; the wider it is, the greater difficulty to make the wheels fit that head. The drivers will crush the outer edges of the head, because they will bear heavier on the outer edges than the car wheels will. It is a question of the elastic limit of metal.

J. B. JOHNSON, M. Am. Soc. C. E.—I don't think there is any discrepancy in theory between the increased flow of rails under slow loads, and the increased load on a bridge under a fast train. We all understand that iron and steel are plastic bodies which flow the same as any other plastic body. We know that if we take a cake of wax and strike it with a hammer it flies to pieces; but if a very small weight be left upon that wax a few hours it will settle itself into it. The distortion of a plastic body results more from the length of time during which the force is applied, than from the amount of force. If the force applied to this iron beyond the elastic limit is increased, the amount of flow will be almost directly proportioned to the time during which the force is applied. In the case of a bridge resisting the force of impact, the suddenness of the load is in proportion to the speed of the train. If the load be instantly imposed, the effect of the load is twice the static load, so that both these results are according to theory and they are not at all in conflict.

The wheels of locomotives and of cars are not and will not be of the same shape, since locomotive drivers will grind themselves badly. The average condition of the car wheel will be somewhat conical and a worn driver will always be grooved. It is difficult to say what the surface of the rail should be; but we may say this, that the shape which the locomotive driver finally attains as the effect of grinding on the track

depends on the original shape of the rail. If you have a rail that was originally sloped inward, and the driver grinds upon such a rail, it would grind to such a slope. If the rail is flat on top and the driver grinds it, it will grind to a horizontal shape. I have wondered whether the rail head could not be rolled to a slight slope, so that the final slope of the rail would be that of its original slope. We know that when a new rail is put down, the bearing will be really on a quarter of an inch of the width of the rail, so that the rail is but a quarter of an inch in width, in fact, but when the rail has worn down, it always has a slope inward; this inward slope depending, in form, on its original form, and on those of the wheels running upon it. Why should not the rail be rolled to that shape in the beginning, so that it would bear over a large surface, just as when the rail becomes worn? The final shape we find is the result of the original; if we would give to the rail this final shape originally, then there is no reason why the shape should change. I would like to ask the practical men what is the objection to rolling rails slightly sloping to the inside?

Mr. GOTTLIEB.—It could be done, but it would be poor economy to do it; but there is a very simple way to obtain the same result. On the European roads, or at least on the German roads, they give the rail the proper inclination by adzing or notching the cross-tie at the rail seat, which gives the same effect.

Mr. J. T. DODGE.—Embracing the opportunity offered by a view of the foregoing discussion, I would remark that my subsequent observations confirm the facts stated in my original paper, viz., that a large amount of the destruction of rails is due to a flow of the metal.

Mr. Francis stated the deduction from the facts very concisely and correctly. Mr. Becker expressed a doubt of the facts and at the same time suggested the sliding of the wheels as an explanation of them.

This being a question of fact, it is better to appeal to observation than to argument. If observation does not confirm the statements made, then the evil does not exist as stated.

While the whole of the discussion is highly interesting and instructive, much of it is not strictly pertinent, and hence is out of the range of my inquiry.